# Upper Penitencia Creek Sediment Source Assessment

*Technical Memorandum*

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# Table of Contents

**1 INTRODUCTION ..... 3**
1.1 Goals ..... 3
1.2 Objectives ..... 3
**2 METHODS ..... 4**
2.1 Existing Data ..... 4
*2.1.1 United States Geological Survey Open-File Report 98-795 ..... 4*
*2.1.2 Alum Rock Park Management Plan ..... 4*
*2.1.3 Upper Penitencia Creek Reconnaissance Level Sediment Assessment ..... 4*
*2.1.4 Upper Penitencia Creek Limiting Factors Analysis ..... 5*
*2.1.5 Hydrologic information ..... 5*
*2.1.6 Historical aerial photography ..... 6*
2.2 Hillslope and Channel Field Surveys ..... 6
**3 RESULTS ..... 6**
3.1 Sediment Sources from Historical Aerial Photography ..... 6
*3.1.1 1984 ..... 7*
*3.1.2 1990 ..... 11*
*3.1.3 1998-1999 ..... 11*
3.2 Sediment Sources from April 2007 Field Reconnaissance ..... 11
**4 DISCUSSION ..... 12**
4.1 Apparent Influence of Human Activity ..... 12
*4.1.1 Roads ..... 13*
*4.1.2 Grazing ..... 13*
*4.1.3 Channel Management ..... 15*
4.2 Priority Concerns for Controlling Sediment Production ..... 16
4.3 Recommendations for Reducing Sediment Production ..... 17
4.4 Recommended Future Studies ..... 18
**5 REFERENCES ..... 19**

## Appendices

Appendix A. Landslide Gazetteer
Appendix B. Road-Related Landslide Gazetteer

## Tables

Table 2-1. The highest recorded mean daily streamflow values recorded at the Upper Penitencia at Dorel Drive (Santa Clara Valley Water District # SF 83). ........ 6
Table 3-1. The number and area ($m^2$) of landslides observed in 1984, 1990, and 1998-1999 aerial photographs. ........ 7
Table 3-2. The number and area ($m^2$) of landslide by lithologic unit for each photo year. ........ 8
Table 3-3. The number and area ($m^2$) of landslide by vegetation type for each photo year. ........ 9
Table 3-4. The number and area ($m^2$) of landslide by vegetation type and lithologic unit for each photo year. ........ 10
Table 4-1. The number and area ($m^2$) of active road related landslides observed in 1984, 1990, and 1998-1999 aerial photographs. ........ 13
Table 4-2. RUSLE2-derived estimates of sediment yield under grazed and ungrazed conditions. Assumed grazed area of 13 $km^2$. ........ 14
Table 4-3. Comparison between estimated unconfined and confined bankfull channel dimension. ........ 16
Table 4-4. Priority concerns for controlling sediment production determined from field reconnaissance and aerial photography. ........ 16

## Figures

Figure 1-1. Study Area map.
Figure 2-1. Landslides from existing sources.
Figure 2-2. Mean daily streamflow in Upper Penitencia Creek at SCVWD gage SF 83 at Dorel Drive, Water Years 1962–2004.
Figure 3-1. Landslide activity, 1984.
Figure 3-2. Landslide activity, 1990.
Figure 3-3. Landslide activity, 1998-1999.
Figure 3-4 a. Field mapped landslides, 2007.
Figure 3-4 b. Field mapped landslides, 2007.
Figure 4-1. Road associated active features.
Figure 4-2a. Priority concerns for controlling sediment production.
Figure 4-2b. Priority concerns for controlling sediment production.

# 1 INTRODUCTION

This report presents the results of studies and information synthesis conducted by Stillwater Sciences to locate and characterize sediment sources within the Upper Penitencia Creek basin, in Santa Clara County, California. This study was funded by the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP), as part of SCVURPPP's efforts to assess sediment-related impacts to beneficial uses in Upper Penitencia Creek and other streams in the Santa Clara Valley. Upper Penitencia Creek is among the streams previously identified by SCVURPPP as high priority for watershed analysis due to the potential for anthropogenic sediment impairment.

The Upper Penitencia Creek Limiting Factors Analysis (LFA) analyzed sediment related factors limiting the steelhead trout (*Oncorhynchus mykiss*) population and produced key findings that were the basis of this study (Stillwater Sciences 2006). The LFA found that overwintering habitat was likely a key limiting factor, specifically the embedding of coarse substrate, such as cobbles and boulders, which reduced the availability of interstitial space used by overwintering steelhead. However, existing information was not sufficient to differentiate current anthropogenic sediment inputs from what was likely a naturally high sediment yield from the basin. A sediment source assessment was recommended to characterize anthropogenic fine sediment contributions.

The Study Area for this sediment source assessment encompassed the Upper Penitencia Creek from the basin divide to the downstream edge of Alum Rock Park (Figure 1-1). This portion of the basin, near the confluence of Upper Penitencia and Arroyo Aguague Creeks was previously described as the "heart" of the basin, and a key element in sediment production and delivery (PWA 2001). The reader is referred to Stillwater Sciences (2006) for detailed descriptions of physical setting, and current and past land-use within the basin.

## 1.1 Goals

The goals of the sediment source assessment are to:

1. Identify and locate sediment sources in the upper part of the Upper Penitencia Creek basin using repeat large-scale aerial photographs and limited field reconnaissance, building on previous studies where possible (Sections 2 and 3);
2. Characterize the apparent influence of human activities on sediment sources in the watershed (Section 4.1);
3. Identify priority concerns and locations for controlling sediment production and deposition that may impact juvenile steelhead overwintering habitat, with a focus on sources associated with urban runoff (i.e. roads). (Section 4.2);
4. Recommend general management actions to reduce sediment production from high priority locations (Section 4.3);
5. Provide the foundation for future analyses of sediment production, delivery, and yield, which can more thoroughly describe and potentially address sediment-related management issues in an effective and process-oriented manner. (Section 4.4).

## 1.2 Objectives

The objectives of the Upper Penitencia Creek Sediment Source Assessment are to locate and characterize discrete sediment sources identified on aerial photographs and in the field, and to attribute these sediment sources to natural processes or human actions. Further, the sediment source assessment identifies priority locations for controlling sediment production and delivery. This sediment source assessment relies on historical data sources (aerial photographs, previous reports) and limited field reconnaissance to meet the above objectives and to develop a prioritized list of recommendations of erosion and sediment management actions. Grazing-related disturbance may occur within the basin, but is primarily a non-point sediment source and so difficult to characterize in the field. In addition, grazed lands were largely inaccessible during field survey. Consequently, a simple model is used to assess potential grazing impact. A very general assessment of channel management impacts is also provided.

# 2 METHODS

## 2.1 Existing Data

We reviewed existing data to determine the extent of previous sediment source mapping, and to determine the results of past management reports. This section summarizes the main data sources consulted during this review.

### 2.1.1 United States Geological Survey Open-File Report 98-795

Wentworth et al. (1999) compiled existing geologic information, along with new mapping data, for the San Jose 30 by 60 minute quadrangle, comprised of thirty two 7.5 minute quadrangles, at a scale of 1:24,000. As part of this report, landslides in the Study Area were mapped via original photointerpretation from 1:80,000 aerial photographs, and as such, features shown on the maps are larger >200 m across. The maps show most landslides occurring along the mainstem of Upper Penitencia Creek within the Great Valley Sequence, Monterey Formation, and Briones Sandstone lithologic units, and between the Upper Penitencia Creek/Arroyo Aguague confluence and Cherry Flat Reservoir within Briones Sandstone and Franciscan Formation, and along Arroyo Aguague within Briones Sandstone and Franciscan Formation (Figure 2-1).

### 2.1.2 Alum Rock Park Management Plan

The Alum Rock Park Riparian Management Plan (BRG 2001) presented strategies to protect and restore riparian and aquatic resources along the portion of Upper Penitencia Creek within Alum Rock Park. The report contains a description of landslides within the park, including a map of large scale quaternary landslides and a field based geologic observation map that delineated a subset of smaller scale features located mostly within weak, older fluvial materials along the south-facing north wall of the Alum Rock Park canyon walls (Figure 2-1). Within the Alum Rock Park canyon, slope inclination and strength of underlying materials were the major controls on smaller scale features, with most occurring on exposed steep slopes of the Great Valley Sequence between the Berryessa and Warm Springs fault zones.

### 2.1.3 Upper Penitencia Creek Reconnaissance Level Sediment Assessment

Philip Williams and Associates (2001) conducted a reconnaissance-level sediment assessment as part of an existing conditions summary for a proposed flood control project along the lower portion of Upper Penitencia Creek where it flows across the Santa Clara Valley. The assessment used a basin-scale approach to describe sediment sources, outlining process domains based on geology, soil type, and predominant land use occurring upstream of the proposed project. The reconnaissance survey qualitatively described sources of channel sediment, noting that large amounts of bed material, derived directly from bedrock or from deep gullies, was available for transport. Major hillslope processes noted in the upper watershed were mass movement in the form of rockfall occurring on steep slopes near the confluence of Upper Penitencia Creek and Arroyo Aguague that contributed coarse material, and shallow-seated mudsliding occurring on forested valley sides that contributed fine sediment. The assessment also noted that fine and coarse sediment is produced through gully erosion stemming from tributary rejuvenation caused by incision in mainstem channels, and flow concentration into small tributaries and the development of rills and gullies caused by grazing and road drainage.

### 2.1.4 Upper Penitencia Creek Limiting Factors Analysis

The Upper Penitencia Creek Limiting Factors Analysis (LFA) (Stillwater Sciences 2006) analyzed factors potentially limiting Steelhead trout (*Oncorhynchus mykiss*) production within the basin to determine possible causes of current adverse impacts or historical decline. The LFA included a description of current geomorphic condition based upon the above sources, field reconnaissance, and historical land use. Several channel sediment-related studies were conducted as part of the LFA, focusing on winter habitat suitability, spawning gravel permeability, extent of pool filling by fine sediment (V*). As stated in Section 1, the rearing capacity of juvenile steelhead was likely limited by the intrusion of sediment into interstices of coarse substrate, such as cobbles and boulders, which reduces the area available for concealment and velocity refuge during high winter flows. The field reconnaissance noted accumulations of sandy clay 0.45–0.60 m (18–24 in) thick stored upstream and downstream of boulders in Upper Penitencia Creek between Cherry Flat Reservoir and the confluence with Arroyo Aguague, and pockets of gravelly sand stored upstream and downstream of large boulders in Arroyo Aguague between the confluence with Upper Penitencia Creek and an upstream waterfall. It was not possible to determine if these pockets of fine sediment were attributable to naturally high sediment yield of erosive parent material, tectonic activity, and episodic rainfall, or represented an elevated production in response to adjacent land uses, such as grazing and roads. The spawning gravel permeability study found that permeability was insufficient to support a high level of egg survival and that fine sediment concentrations in the channel bed subsurface may adversely affect embryo survival. However, as steelhead only need limited spawning habitat quantity and quality to effectively seed the available rearing habitat, spawning gravel permeability was likely not a limiting factor. The mean level of pool filling was found to be relatively low compared to literature values for similar terrain types and was not limiting juvenile steelhead rearing habitat.

### 2.1.5 Hydrologic information

Streamflow data for the Study Area was obtained from the Upper Penitencia Creek at Dorel Drive stream gage (Santa Clara Valley Water District Gage #SF 83, October 1961 to present) to determine the recent occurrence of storms within the study area. Figure 2-2 shows the mean daily flow (cfs) and Table 2-1 shows the highest mean daily flows for the period of record. Based on these data, wettest conditions in the watershed (associated with the highest stream flows) occurred (highest first) in 1980, 1982, 1995, 1986, 1997, and 1983.

**Table 2-1.** The highest recorded mean daily streamflow values recorded at the Upper Penitencia at Dorel Drive (Santa Clara Valley Water District # SF 83).

| Date | Mean daily value ($m^3s$-$^1$) | Mean daily value (cfs) |
|---|---|---|
| 2/19/80 | 15.4 | 545 |
| 3/31/82 | 13.4 | 473 |
| 3/23/95 | 12.8 | 453 |
| 2/17/86 | 10.6 | 375 |
| 1/26/97 | 10.4 | 369 |
| 3/1/83 | 10.3 | 364 |

### 2.1.6 Historical aerial photography

Large scale (1:12,000) sequential historical aerial photographs from 1984, 1990, and 1998-1999 were acquired to establish a time reference for landslide initiation and reactivation history and correspondence with potential landslide-triggering storm events, detect changes in land use/cover type, and determine hillslope response to storm events or road construction. The aerial photographs also provided evidence to validate the existence and/or magnitude of erosion for previously mapped sediment sources and establish a time series record of erosion across the Study Area since 1984. On all sets of aerial photographs, active and dormant features were identified and described according to feature type, lithologic unit (as observed on a geologic map), vegetative cover (as observed on the photograph), and road association. The area of each feature (as measured from the aerial photographs) was estimated to quantify the areal extent of landslide features over the study period. We categorized features by lithologic unit and vegetative cover to describe sediment sources over the period of record, and road association to estimate the apparent influence of human activity within the Study Area. Dormant features that were mapped on the 1984 photographs and that were also dormant on the 1990 and 1998–1999 photographs were not mapped again. Therefore, only results from the 1984 analysis show the total number of dormant features.

## 2.2 Hillslope and Channel Field Surveys

From 16 to 20 April 2007, a two-person field crew conducted surveys along channels and hillslopes within the Study Area to document a sub-sample of erosion occurring across varying lithologic units and land uses, as access allowed. The surveys characterized landslides by type, lithologic unit, vegetative cover, and road association, and noted eroded site dimensions to estimate volume.

# 3 RESULTS

## 3.1 Sediment Sources from Historical Aerial Photography

The results below discuss landslides according to four activity states (from Cruden and Varnes 1996) but focuses on active features that are the most sensitive to current land use and management actions. The four activity states include:

- active: apparent recent movement,
- active/suspended: no recent movement <100 yrs old,

- inactive: no recent movement 100-10,000 yrs old, and
- dormant: no recent movement likely >10,000 yr old.

### 3.1.1 1984

We found 134 landslides on the 1984 aerial photographs, including 62 active, 23 active/suspended, 34 inactive, and 15 dormant features (Table 3-1 and Figure 3-1). Many of the active features were likely in response to wet conditions experienced in 1980, 1982, and 1983. The greatest occurrences of active landslides occurred within Franciscan Complex and Briones Sandstone lithologic units (Table 3-2), and within grassland and shrubland vegetation types (Table 3-3). Seventeen debris slides were also observed within unvegetated inner gorge areas. The lithologic unit and vegetation types with the greatest number of landslides were Franciscan Complex-shrubland, and Franciscan Complex-grassland (Table 3-4) and the most abundant active features within these areas were debris slides (Appendix A).

**Table 3-1.** The number and area ($m^2$) of landslides observed in 1984, 1990, and 1998-1999 aerial photographs.

| **Activity Status** | **Photo Year** | | | | | |
|---|---|---|---|---|---|---|
| | **1984** | | **1990** | | **1998-99** | |
| | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** |
| Active | 62 | 628,997 | 35 | 320,861 | 35 | 1,152,336 |
| Active suspended | 23 | 647,001 | 8 | 128,170 | 9 | 77,320 |
| Inactive | 34 | 1,050,658 | 5 | 262,513 | 4 | 45,702 |
| Dormant | 15 | 2,535,451 | 6 | 937,131 | 5 | 239,457 |
| **TOTAL** | **134** | **4,862,108** | **54** | **1,648,675** | **53** | **1,514,815** |

The area of landslides mapped from the 1984 aerial photographs was approximately 4,860,000 $m^2$, including 629,000 $m^2$ of active landslides (Table 3-1). The greatest area of active landslides occurred within the Briones Sandstone and Franciscan Complex, mainly as debris slides (Table 3-2), and within shrubland and forest/shrub vegetation units, as debris slides and debris slide slopes, and one rotational landslide (Table 3-3). The geology-land cover associations with the greatest area of landslides were Briones Sandstone -shrubland and -forest/shrub (Table 3-4).

**Table 3-2.** The number and area ($m^2$) of landslide by lithologic unit for each photo year.

| Photo Year | Feature Type | Lithologic Unit | | | | | | | | GRAND TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Franciscan | | Great Valley | | Briones sandstone | | Monterey group | | | |
| | | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) |
| 1984 | Channel bank erosion | 3 | 9,816 | | | | | | | 3 | 9,816 |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | 21 | 83,126 | 4 | 8,970 | 14 | 157,245 | | | 39 | 249,340 |
| | Debris slide slope | 1 | 21,546 | | | 1 | 138,589 | | | 2 | 160,135 |
| | Earthflow | | | | | | | | | | |
| | Gully | 9 | 23,647 | | | | | 1 | 1,060 | 10 | 24,706 |
| | Rock slide | | | | | | | 1 | 5,651 | 1 | 5,651 |
| | Sheetwash/rill erosion | 5 | 37,738 | | | | | | | 5 | 37,738 |
| | Slump earthflow | 1 | 1,329 | | | | | | | 1 | 1,329 |
| | Translational/rotational | | | | | 1 | 140,281 | | | 1 | 140,281 |
| | **TOTAL** | **40** | **177,201** | **4** | **8,970** | **16** | **436,115** | **2** | **6,711** | **62** | **628,997** |
| 1990 | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | 4 | 9,440 | 2 | 1,452 | 13 | 199,699 | | | 19 | 210,591 |
| | Debris slide slope | | | 1 | 23,964 | 1 | 46,475 | | | 2 | 70,439 |
| | Earthflow | | | | | | | | | | |
| | Gully | 7 | 15,141 | | | 1 | 3,086 | | | 8 | 18,227 |
| | Rock slide | | | | | 2 | 10,166 | 1 | 3,631 | 3 | 13,797 |
| | Sheetwash/rill erosion | 1 | 2,542 | | | | | | | 1 | 2,542 |
| | Slump earthflow | 2 | 5,265 | | | | | | | 2 | 5,265 |
| | Translational/rotational | | | | | | | | | | |
| | **TOTAL** | **14** | **32,387** | **3** | **25,416** | **17** | **259,427** | **1** | **3,631** | **35** | **320,861** |
| 1998-1999 | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | 1 | 19,970 | | | | | | | 1 | 19,970 |
| | Debris flow | | | | | 1 | 46,104 | | | 1 | 46,104 |
| | Debris slide | 1 | 5,083 | | | 13 | 582,484 | 1 | 7,625 | 15 | 595,192 |
| | Debris slide slope | | | | | 2 | 66,536 | | | 2 | 66,536 |
| | Earthflow | | | | | | | | | | |
| | Gully | 8 | 28,139 | | | 2 | 49,465 | | | 10 | 77,604 |
| | Rock slide | | | | | | | 2 | 83,510 | 2 | 83,510 |
| | Sheetwash/rill erosion | 2 | 261,424 | | | | | | | 2 | 261,424 |
| | Slump earthflow | 1 | 1,089 | | | | | | | 1 | 1,089 |
| | Translational/rotational | | | | | | | 1 | 908 | 1 | 908 |
| | **TOTAL** | **13** | **315,705** | | | **18** | **744,588** | **4** | **92,043** | **35** | **1,152,336** |

**Table 3-3.** The number and area ($m^2$) of landslide by vegetation type for each photo year.

| **Photo Year** | **Feature Type** | **Vegetation Type** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Forest** | | **Forest/shrub** | | **Grassland** | | **Riparian** | | **Shrub/forest** | | **Shrubland** | | **Unvegetated** | | **GRAND TOTAL** | |
| | | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** |
| **1984** | Channel bank erosion | | | | | 1 | 846 | | | | | 1 | 7,947 | 1 | 1,022 | 3 | 9,816 |
| | Channel head advance | | | | | | | | | | | | | | | | |
| | Debris flow | | | | | | | | | | | | | | | | |
| | Debris slide | | | 1 | 40,601 | 4 | 13,366 | 4 | 40,573 | 2 | 32,217 | 11 | 90,339 | 17 | 32,245 | 39 | 249,340 |
| | Debris slide slope | | | | | | | | | | | 2 | 160,135 | | | 2 | 160,135 |
| | Earthflow | | | | | | | | | | | | | | | | |
| | Gully | 1 | 1,060 | | | 7 | 13,032 | 1 | 7,733 | | | 1 | 2,881 | | | 10 | 24,706 |
| | Rock slide | | | | | | | | | | | | | 1 | 5,651 | 1 | 5,651 |
| | Sheetwash/rill erosion | | | | | 5 | 37,738 | | | | | | | | | 5 | 37,738 |
| | Slump earthflow | | | | | 1 | 1,329 | | | | | | | | | 1 | 1,329 |
| | Translational/rotational | | | 1 | 140,281 | | | | | | | | | | | 1 | 140,281 |
| | **TOTAL** | **1** | **1,060** | **2** | **180,882** | **18** | **66,311** | **5** | **48,306** | **2** | **32,217** | **15** | **261,303** | **19** | **38,918** | **62** | **628,997** |
| **1990** | Channel bank erosion | | | | | | | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | | | | | | | |
| | Debris flow | | | | | | | | | | | | | | | | |
| | Debris slide | | | | | | | 1 | 1,089 | 1 | 21,604 | 7 | 93,132 | 10 | 94,766 | 19 | 210,591 |
| | Debris slide slope | | | | | | | | | | | 2 | 70,439 | | | 2 | 70,439 |
| | Earthflow | | | | | | | | | | | | | | | | |
| | Gully | | | | | 4 | 4,611 | | | | | 2 | 5,265 | 2 | 8,351 | 8 | 18,227 |
| | Rock slide | | | 1 | 2,542 | | | | | | | | | 2 | 11,256 | 3 | 13,797 |
| | Sheetwash/rill erosion | | | | | | | | | | | | | 1 | 2,542 | 1 | 2,542 |
| | Slump earthflow | | | | | 1 | 1,452 | | | 1 | 3,812 | | | | | 2 | 5,265 |
| | Translational/rotational | | | | | | | | | | | | | | | | |
| | **TOTAL** | | | **1** | **2,542** | **5** | **6,064** | **1** | **1,089** | **2** | **25,416** | **11** | **168,836** | **15** | **116,914** | **35** | **320,861** |
| **1998-1999** | Channel bank erosion | | | | | | | | | | | | | | | | |
| | Channel head advance | | | | | 1 | 19,970 | | | | | | | | | 1 | 19,970 |
| | Debris flow | | | | | | | | | | | 1 | 46,104 | | | 1 | 46,104 |
| | Debris slide | | | 1 | 24,508 | | | | | 2 | 157,774 | 3 | 64,993 | 9 | 347,916 | 15 | 595,192 |
| | Debris slide slope | | | | | | | | | | | | | 2 | 66,536 | 2 | 66,536 |
| | Earthflow | | | | | | | | | | | | | | | | |
| | Gully | | | | | 8 | 71,165 | 1 | 4,357 | | | 1 | 2,082 | | | 10 | 77,604 |
| | Rock slide | | | | | | | | | | | | | 2 | 83,510 | 2 | 83,510 |
| | Sheetwash/rill erosion | | | | | 2 | 261,424 | | | | | | | | | 2 | 261,424 |
| | Slump earthflow | | | | | 1 | 1,089 | | | | | | | | | 1 | 1,089 |
| | Translational/rotational | | | | | | | | | | | | | 1 | 908 | 1 | 908 |
| | **TOTAL** | | | **1** | **24,508** | **12** | **353,648** | **1** | **4,357** | **2** | **157,774** | **5** | **113,178** | **14** | **498,870** | **35** | **1,152,336** |

**Table 3-4.** The number and area (m$^2$) of landslide by vegetation type and lithologic unit for each photo year.

| **Photo Year** | **Vegetation Type** | **Lithologic Unit** | | | | | | | | **GRAND TOTAL** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Franciscan** | | **Great Valley** | | **Briones sandstone** | | **Monterey group** | | | |
| | | **#** | **Area (m$^2$)** | **#** | **Area (m$^2$)** | **#** | **Area (m$^2$)** | **#** | **Area (m$^2$)** | **#** | **Area (m$^2$)** |
| **1984** | Forest | | | | | | | 1 | 1,060 | 1 | 1,060 |
| | Forest/shrub | | | | | 2 | 180,882 | | | 2 | 180,882 |
| | Grassland | 18 | 66,311 | | | | | | | 18 | 66,311 |
| | Riparian | 3 | 20,412 | | | 2 | 27,894 | | | 5 | 48,306 |
| | Shrub/forest | | | | | 2 | 32,217 | | | 2 | 32,217 |
| | Shrubland | 12 | 79,622 | | | 3 | 181,681 | | | 15 | 261,303 |
| | Unvegetated | 7 | 10,857 | 4 | 8,970 | 7 | 13,441 | 1 | 5,651 | 19 | 38,918 |
| | **TOTAL** | **40** | **177,201** | **4** | **8,970** | **16** | **436,115** | **2** | **6,711** | **62** | **628,997** |
| **1990** | Forest | | | | | | | | | | |
| | Forest/shrub | | | | | 1 | 2,542 | | | 1 | 2,542 |
| | Grassland | 5 | 6,064 | | | | | | | 5 | 6,064 |
| | Riparian | 1 | 1,089 | | | | | | | 1 | 1,089 |
| | Shrub/forest | 1 | 3,812 | | | 1 | 21,604 | | | 2 | 25,416 |
| | Shrubland | 3 | 7,625 | 2 | 24,690 | 6 | 136,521 | | | 11 | 168,836 |
| | Unvegetated | 4 | 13,797 | 1 | 726 | 9 | 98,760 | 1 | 3,631 | 15 | 116,914 |
| | **TOTAL** | **14** | **32,387** | **3** | **25,416** | **17** | **259,427** | **1** | **3,631** | **35** | **320,861** |
| **1998-1999** | Forest | | | | | | | | | | |
| | Forest/shrub | | | | | 1 | 24,508 | | | 1 | 24,508 |
| | Grassland | 11 | 306,265 | | | 1 | 47,383 | | | 12 | 353,648 |
| | Riparian | 1 | 4,357 | | | | | | | 1 | 4,357 |
| | Shrub/forest | | | | | 2 | 157,774 | | | 2 | 157,774 |
| | Shrubland | 1 | 5,083 | | | 3 | 100,470 | 1 | 7,625 | 5 | 113,178 |
| | Unvegetated | | | | | 11 | 414,452 | 3 | 84,418 | 14 | 498,870 |
| | **TOTAL** | **13** | **315,705** | | | **18** | **744,588** | **4** | **92,043** | **35** | **1,152,336** |

### 3.1.2 1990

Results of mapping from the 1990 aerial photographs found 54 landslides, including 35 active and 6 dormant (Table 3-1 and Figure 3-2). The highest flow between 1984 and 1990 occurred in 1986 (Table 2-1), and active features seen within the photographs likely reflect a response to the associated storm. Most of the 35 active features occurred within the Briones Sandstone formation as debris slides and the Franciscan Complex as gullies (Table 3-2) and within shrubland or unvegetated (inner gorge) areas (Table 3-3). The Briones Sandstone-unvegetated (inner gorge) (debris slides), Briones Sandstone -shrubland (debris slides), and Franciscan Complex -grassland (gullies) were the most active geology-land cover associations (with most common feature type) (Table 3-4 and A.2).

We mapped approximately 1,649,000 $m^2$ of landslides from the 1990 aerial photographs, including 321,000 $m^2$ of active landslides (Table 3-1). The greatest area occurred within the Briones Sandstone and Franciscan Complex lithotypes, and within shrubland and unvegetated (inner gorge) areas as debris slides and debris slide slopes (Tables 3-2 and 3-3). The geology-land cover associations with the greatest area of landslides were Briones Sandstone-shrubland and -unvegetated (inner gorge), and Great Valley Sequence-shrubland (Table 3-4).

### 3.1.3 1998-1999

The 1998-1999 aerial photographs showed 53 landslides, including 35 active and 5 dormant (Table 3-1). Wet conditions since 1990 occurred in 1995, and 1997, and active features likely reflect these events. As in the 1984 and 1990 photographs, most active features occurred within the Briones Sandstone and the Franciscan Complex (Table 3-2 and Figure 3-3) as debris slides and gullies, and within unvegetated (inner gorge) areas, as debris slides, or within grasslands, as gullies (Table 3-3). The Briones Sandstone -unvegetated (inner gorge) (debris slides) and Franciscan Complex -grassland (gullies) were the most active geology-land cover associations (with most common feature type) (Table 3-4 and A.3).

We mapped approximately 1,515,000 $m^2$ of landslides from the 1998-1999 aerial photographs, including 1,152,000 $m^2$ of active landslides (Table 3-1). The greatest area occurred within the Briones Sandstone and Franciscan Complex, and within unvegetated (inner gorge) areas and grasslands as debris slides, debris slide slopes, and sheetwash/rill erosion (Tables 3-2 and 3-3). The geology-land cover associations with the greatest area of landslides were Briones Sandstone -unvegetated (inner gorge) and -shrub/forest, and Franciscan Complex -grassland (Table 3-4).

## 3.2 Sediment Sources from April 2007 Field Reconnaissance

Field surveys occurred along Upper Penitencia Creek between Cherry Flat Reservoir and the confluence with Arroyo Aguague, along an unnamed Upper Penitencia Creek tributary that enters just upstream of the confluence with Arroyo Aguague, along Arroyo Aguague within Alum Rock Park, and along Arroyo Aguague headwater reaches and tributaries near the upper portions of the basin (Figures 3-4a and b). Thirty-two active sediment sources were identified and mapped during the April 2007 field reconnaissance. Twelve features from the aerial photographs were validated during the survey and the remaining features were in-channel and hillslope features not visible on the photographs. The largest volumetrically observed features were associated with an active rockslide within Alum Rock Park, active gully erosion occurring downstream of an abandoned reservoir along a tributary to Upper Penitencia Creek between its confluence with

Arroyo Aguague and Cherry Flat Reservoir, road related gullying along the headwaters of Arroyo Aguague, and bioturbation, likely from rooting by feral pigs.

# 4 DISCUSSION

Upper Penitencia Creek basin is comprised of four major geologic units interspersed between the Hayward and Calaveras strike-slip fault zones. The fault zones run approximately parallel to one another in a north-south direction, with the Calaveras fault running across the ridgetops at the basin divide. The basin is underlain by the Franciscan formation, which is exposed on the eastern side of the Calaveras fault. All the units are deformed by strong seismic activity occurring between the two fault systems (BRG 2001), resulting in locally very steep topography and highly erosion-prone surficial geology and soils. This combination of factors combined with the intense, episodic winter rainfall characteristic of California's Mediterranean climate, likely combine to produce a naturally high sediment load in Upper Penitencia Creek. Importantly, the steep topography, erosion-prone soils, and intense rainfall potential make the watershed very sensitive to disturbances such as those associated with human activities.

## 4.1 Apparent Influence of Human Activity

Sediment production within a given watershed results from a discrete set of geomorphic processes. The processes occur naturally, but are frequently accentuated by human activities resulting in "excess" sediment production, identifiable on the landscape by an increased frequency and volume of sediment sources. Because data rarely exist to determine the frequency and volume of sources free of human influence, the effect of human activity on sediment production is generally determined by the association of sources with particular land covers or land cover change, or specific land and river management activities. Human activities also tend to result in the preferential release of fine sediment into watercourses that can impair ecological processes, such as excess fine sediment ingress into salmonid over-wintering habitat provided by the interstices between coarse sediment. Some sediment sources are very clearly associated with human actions, such as erosion related to road drainage or sources stemming from road surface erosion.

Our survey of historical aerial photography, past reports, and recent field surveys suggest active and frequent landsliding within the Study Area. This survey estimated the abundance and areal extent of landslides and the data indicate that the most prolific sediment source areas within the Upper Penitencia Creek basin were located within the following geology-land cover associations:

- Briones Sandstone-unvegetated (inner gorge)
- Briones Sandstone-shrubland
- Franciscan Complex-grassland

The area of discrete active features decreased from 1984 to 1990, suggesting that closely-spaced intense storms of 1980, 1982, and 1983 had a greater impact on landslide activity than the isolated 1986 storm, and increased from 1990 to 1998-1999, suggesting a response to the combination of 1995 and 1997 storms. Unsurprisingly, the data suggest that sediment production from landslides is maximized under conditions of frequent large storm events. The largest areal fluctuations occurred within the Franciscan Complex-grassland and Briones Sandstone-unvegetated (inner gorge) (Table 3-4), suggesting that these associations are the most responsive to large storms, and are likely sensitive to effects from land use.

### 4.1.1 Roads

We found that the existence of the roads and road drainage tends to be the source of persistent sediment production based on the number and area of active landslides visible on aerial photographs from the 1980s and 1990s. Table 4-1 (see also Appendix B) indicates that, while the total number and area of road-related landslides fluctuates through time in our survey, the area per landslide consistently increases, from 4,600 $m^2$ per landslide in 1984, to 12,100 $m^2$ per landslide in 1998-99 (10,500 $m^2$ per landslide in 1990). Our inference is that road-related sediment production, once triggered by large storm events, persists in time possibly as later storm flows are concentrated in landslide scars. The location of road related features occurs adjacent to roads along the northwestern (within Briones Sandstone) and southeastern (within Franciscan Complex) portions of the Study Area, suggesting an ongoing source of anthropogenic sediment (Figure 4-1)

**Table 4-1.** The number and area ($m^2$) of active road related landslides observed in 1984, 1990, and 1998-1999 aerial photographs.

| Lithologic Unit | Photo Year | | | | | |
|---|---|---|---|---|---|---|
| | 1984 | | 1990 | | 1998-99 | |
| | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) |
| Franciscan | 7 | 18,469 | 7 | 13,725 | 6 | 28,049 |
| Great Valley | | | 3 | 25,416 | | |
| Briones sandstone | 8 | 50,398 | 9 | 159,759 | 5 | 109,728 |
| Monterey group | | | | | 1 | 7,625 |
| **TOTAL** | **15** | **68,867** | **19** | **198,900** | **12** | **145,402** |

### 4.1.2 Grazing

Grazing occurs on private lands upstream of Alum Rock Park in the Upper Penitencia Creek (Buchan *et al.* 1999, EOA 2003) and Arroyo Aguague drainages (SCBWMI 2003). The intensity of the grazing is unknown, as most of the grazed areas are privately owned with few access roads. Upper watershed areas are also impacted to some degree from the presence of feral pigs. Bioturbation, likely from rooting by feral pigs, was observed in the upper areas of the Arroyo Aguague sub-basin during field reconnaissance conducted for this study. Both grazing by cows and feral pig activity can create several potential impacts, including soil compaction, loss of vegetative cover, alteration of plant species composition, and destabilization of hillslopes and stream banks (Mount 1995). Soil compaction reduces infiltration capacity and increases runoff to speed gully formation. The loss of vegetative cover reduces rainfall interception to further increase runoff and erosion, and may increase stream temperatures if riparian canopy cover is reduced. Removal of native grassland species intensifies the increases in runoff and erosion, as native species bind soils more cohesively than exotic annual grasses. Along the stream corridor, livestock and feral pigs can feed on riparian seedlings, preventing regeneration and destabilizing banks. In some cases, such as below Cherry Flat Reservoir, cattle are allowed access to the channel (EOA 2003). Feral pigs root in search of insects and tubers, overturning and loosening the soil, increasing the soil's susceptibility to erosion (Peart et al. 1994).

To provide some basis for understanding potential sediment production from grazed lands, we applied a simple soil erosion model to grazed parts of the study area. The US Department of Agriculture's Universal Soil Loss Equation was developed to predict annual sediment losses from sheetwash and rill erosion using the equation:

$$A = RKLSCP$$

Where, A is the average annual erosion rate (mass/area) for the slope length $\lambda$, R is the erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the cover-management factor, and P is the support practice factor (Foster 2003). We used the Revised Universal Soil Loss Equation, version 2 (RUSLE2), a computer program that makes estimates based upon site specific conditions: climate (determined by location), inherent soil properties (including soil erodibility), topography, and land use. The Natural Resource Conservation Service offers site specific database files for each of these conditions through the RUSLE2 website (NRCS 2008).

The model estimates sediment production only from sheetwash and rill erosion and is frequently misapplied in areas where other erosion processes predominate. Sheetwash and rill erosion does not frequently occur in the California Coast Ranges, but is perhaps most common in moderately-sloped areas under grazing where soil compaction has occurred; uncompacted soils are unlikely to generate sheetwash processes. We estimated total annual sediment yield (tonnes/yr) for the Study Area by assuming the grazing occurs on hillslopes of less than 20% slope. Within the Upper Penitencia Creek basin, slopes greater than 20% occurred in inner gorges, which generally support other erosional processes such as shallow landsliding. This assumption captured an area of approximately 13 $km^2$ (3,270 ac), encompassing ridgetops while excluding canyons and inner gorge areas. Visually, the resultant distribution of grazing land compares favorably with the pattern that can be identified on aerial photographs.

Annual sediment yields (metric tons per square kilometer) are estimated for the Study Area using RUSLE simulations for grazed and ungrazed conditions, as shown in Table 4-2. This estimate only considers grazed and ungrazed conditions, and does not assess sediment yields under native and non-native vegetation ground cover, which is beyond the capabilities and assumptions of the model. In relative terms, the results indicate that, for the upland portion of the Upper Penitenica Creek basin, far higher rates of sheetwash and rill erosion would be expected under grazed conditions than under dense grass vegetative conditions. As such, it is reasonable to assume that a discernable, mostly fine sediment, signal is associated with grazing in the Upper Penitencia Creek basin.

**Table 4-2.** RUSLE2-derived estimates of sediment yield under grazed and ungrazed conditions. Assumed grazed area of 13 $km^2$.

| Condition | Sediment Yield ($tkm^{-2}yr^{-1}$) | Sediment Yield ($tyr^{-1}$) |
|---|---|---|
| Grazed (range grass[1]) | 884 | 11,500 |
| Ungrazed (dense grass[1]) | 5 | 71 |

[1] Terms used in RUSLE to describe long-term vegetation

Over the entire watershed of Upper Penitencia Creek (62 $km^2$), the estimate for sheetwash and rill erosion averages 185 $tkm^{-2}yr^{-1}$. Due to a lack of existing data to contrast our results, we compared our estimated sediment yield to yields derived from reservoir sedimentation studies, which use sediment accumulation over time (since reservoir construction) to determine sediment yield. Studies on local reservoirs estimated a yield of 816 $tkm^{-2}yr^{-1}$ from Berryessa Creek, and an average rate of 680 t $tkm^{-2}yr^{-1}$ from Crystal Springs Reservoir (San Mateo County) and the Las Trampas Reservoir (Contra Costa County) (Northwest Hydraulic Consultants (1990)). Brown and Jackson (1973) estimate long-term sediment yield from gauging station data from three creeks in the south and central San Francisco Bay as approximately 700 t $tkm^{-2}yr^{-1}$. Both the reservoir sedimentation and gauging station studies include other sediment sources,such as shallow landslides and gully erosion, and accordingly should be expected to be higher than the estimate from Upper Penitencia Creek, which includes only sheetwash and rill erosion. The results appear consistent with this notion, indicating that the estimate may be reasonable.

### 4.1.3 Channel Management

Numerous channel alterations occurred along Upper Penitencia Creek through Alum Rock Park in the latter part of the 19th century through the first half of the 20th century (BRG 2001). Rock walls and other channel modifications (bank revetments, sacked concrete, concrete walls, rock gabions, concrete crib walls) line 80% of the channel length in the park and have prevented natural channel migration, the formation of floodplain surfaces and significant gravel bars, and the recruitment of LWD from the banks (Stillwater Sciences 2006). The structures have also increased water depth, causing an increase in shear stresses on the bed and banks. Accordingly, the bed morphology has responded by downcutting to shallow bedrock and to occasional grade control structures that attempt to control bed elevation.

To estimate channel sediment lost through incision, we estimated average bankfull channel dimensions and area from drainage area using a regional relation for the San Francisco Bay Area (Dunne and Leopold 1978), and compared this to Upper Penitencia Creek channel area (through Alum Rock Park) as estimated from cross-sections surveyed in 2001 (BRG 2001, Figure 8). We chose cross-sections representing stream reaches heavily influenced by rock walls and for the purpose of the analysis, we assumed that the walls were constructed in 1936, the same year as Cherry Flat Reservoir (BRG 2001). Dunne and Leopold (1978) estimate bankfull dimensions and area from field data in San Francisco Bay Area streams with 760 mm annual precipitation. The average annual precipitation for the Study Area is approxaimtely 580 mm, so bankfull area may be overestimated for Upper Penitencia Creek.

The estimated and surveyed bankfull channel dimensions for Upper Penitencia Creek through Alum Rock Park are shown in Table 4-3. Under ‘natural’ bankfull conditions, Upper Penitencia Creek would be expected to have a cross-sectional area of approximately 12 $m^2$. While the surveyed width is similar to the estimated width (consistent with the notion that the creek walls were built to the approximate bankfull width of the channel), the channel depth is approximately three times greater under confined conditions, resulting in a large increase in channel area. Assuming that the rock walls were constructed in 1936, the average annual loss of channel sediment through this reach (1.7 km length) from 1936 to 2001 was 1,250 $m^3yr^{-1}$, a total of 81,400 $m^3$. Assuming that the mean bed sediment bulk density is approximately 2.0 $tm^{-3}$ (Carling and Reader 1982, for gravel bedded rivers with a median bed-particle size between 10 and 100 mm), this suggest an export of approximately 160,000 metric tons of bed material sediment load (2,500 t $yr^{-1}$) since approximately 1936. In reality, as channel bed incision rates tends to maximize quickly in time and then exponentially decay, the bulk of this material was likely exported within a decade or two of channelization, and contemporary erosion rates may be negligible, especially as the channel has eroded to bedrock and grade control structures emplaced.

**Table 4-3.** Comparison between estimated unconfined and confined bankfull channel dimension.

| Cross-section | Width (m) | Depth (m) | Area ($m^2$) |
|---|---|---|---|
| **Estimated[1]** | **12.0** | **1.0** | **12.0** |
| xs10.6[2] | 13.0 | 2.4 | 30.1 |
| xs14.1[2] | 16.6 | 3.9 | 64.0 |
| xs15.0[2] | 19.0 | 3.8 | 71.5 |
| xs16.0[2] | 11.5 | 4.0 | 45.0 |
| xs19.0[2] | 11.1 | 2.2 | 24.7 |
| **Surveyed (mean)** | **14.2** | **3.3** | **47.1** |

[1] Estimated from Dunne and Leopold 1978
[2] Cross section numbers correspond to those shown in BRG (2001) Figure 8

## 4.2 Priority Concerns for Controlling Sediment Production

The priority concerns for controlling sediment production are related to the largest discrete sources observed from aerial photographs since 1984 and from limited field observations. The concerns focus on fine sediment, which results preferentially from hillside mass movements and road-related erosion. As road-related erosion represents an increase over background sediment input, the rate of fine sediment production has increased relative to the natural rate (i.e. without roads). In this regard, we identified four priority concerns for controlling sediment production (Table 4-4 and Figure 4-2):

**Table 4-4.** Priority concerns for controlling sediment production determined from field reconnaissance and aerial photography.

| Priority Concern | Description | Jurisdictional Boundary |
|---|---|---|
| 1 | Gully incision below outlet of reservoir | Santa Clara County Open Space Authority |
| 2 | Road related sediment sources along toe slope | Santa Clara County Department of Roads and Airports |
| 3 | Chronic road failures along Alum Rock Falls Road | City of San Jose |
| 4 | Chronic road related erosion in Joseph Grant County Park | Santa Clara County Department of Parks and Recreation |

These priority concerns represent active, chronic sources of anthropogenic sediment within the Upper Penitencia Creek basin that should be addressed to reduce levels of fine sediment delivery to stream channels. The gully incision below the abandoned reservoir found on Santa Clara County Open Space Authority property is a set of features downstream of a natural seep that was dammed to create a reservoir. The original outlet of the reservoir resulted in rampant channel incision, causing the outlet location to be switched, thereby creating another actively incising feature (D.Newman, *pers. comm*.). The road related erosion concerns are those identified in the photographs and validated in the field, in addition to an area (Priority Concern #2, Figure 4-2) not visible in the aerial photographs, that has actively eroding cutbanks directly adjacent to the channel, and is likely the most prolific road-related sediment source area.

## 4.3 Recommendations for Reducing Sediment Production

This section provides general recommendations for reducing sediment production from priority concern areas that focus on the largest, readily identifiable point sources. These include three landslide features associated with roads, and gully erosion below abandoned reservoir. In addition to remediation efforts focusing on the priority concern areas, an overall strategy to reduce sediment supply to the watershed should include implementation of best management practices in sediment-source-rich geology and land-use associations identified above. Relative to other lithologic units in the Upper Penitencia Creek basin, Briones Sandstone and Franciscan Complex are easily erodible, and combined with seismic activity and punctuated seasonal rainfall, are naturally capable of producing large amounts of sediment.

General recommendations to control road-related sediment production from these areas are:

- Implement and maintain Best Management Practices (BMPs) for unpaved roads as described in California Stormwater Quality Association (CASQA) (2003) (see Table 4-4 below):
- Develop and implement a comprehensive road erosion abatement program in which the worst performing roads are identified and prioritized for remediation
- Where possible, increase infiltration on bare hillslopes by planting native vegetation
- Develop and implement a monitoring program that evaluates the effectiveness of measures taken for source control and link this effort with a component to track changes in inter-gravel fine sediment in receiving waters
- Employ a slope hazard analysis to identify high risk areas and eliminate building new roads within these geology-land cover associations, but if necessary use design standards that “fit the road to the landscape” (Furniss et al 1991):
    - Avoid mid-slope roads in favor of higher flatter areas, while avoiding headwalls that are prone to landslides and are the source of tributary drainages
    - Avoid locating roads along inner gorge areas, which are also prone to landslides
    - Design road to minimize drainage area and infrastructure; avoid modifying natural drainage area and pattern

Expanded anthropogenic activities known to increase the frequency and area of hillslope mass wasting (road building, grazing) should only be implemented if done according to best management practices and with avoidance of high risk areas. The specific effect of seismicity and topography (slope) on the location and areal extent of hillslope mass movement were not evaluated within this sediment source assessment, but these factors likely play an important role and should be evaluated in any future studies.

Based upon aerial photographs and field reconnaissance, chronic road related sediment sources are apparently persisting, rather than healing and becoming dormant. Remedial management actions should be developed and implemented to disconnect road surface runoff from entering the channel network. A typical method often employed involves the placement of gabion rocks, which leaves the cause of the problem, flow concentration from roads or drainage infrastructure, to persist. More holistic management, such as disconnecting and diffusing direct road drains onto hillslopes and planting vegetation, should be considered and employed. Roads that have a continuous surface flow path between the road prism and the stream channel are “hydrologically connected” to the channel network. These roads accelerate runoff, and delivery of sediment and road related pollutants to stream channels. Management actions that disconnect roads from the channel network and disperse, rather than concentrate, runoff to infiltrate into the soil and enter the stream as groundwater. Some suggested recommendations are (Furniss et al. 1991):

- Increase number of cross drains (e.g. culverts, water bars) to reduce flow concentration and encourage infiltration
- Use outslope drainage where possible to disperse runoff and reduce potential for road-related landslides and gullies
- Consider removing non-critical roads or closing roads to eliminate or reduce traffic volume during wet season to reduce road surface and point source erosion. Madej et al. (2006) describes road removal techniques and a method to prioritize road removal on a basin-scale according to cost and effectiveness of removal strategy

Additionally, road rehabilitation within the Upper Penitencia Creek basin should be approached at the basin scale and monitored to determine the effectiveness of the techniques and to validate hypotheses associated with SCVURPPP's effort to assess sediment related impacts to steelhead habitat.

General recommendations to control sediment production from gully erosion below reservoir are:

- Remove earthen dam currently impounding water discharging from seep
- Regrade and revegetate downstream gullies
- Restore former seep/wetland area as critical habitat for sensitive species (e.g., red-legged frog (*Rana draytonii*))

## 4.4 Recommended Future Studies

This study identified the location and area of sediment sources determined from three sets of aerial photographs flown since 1984, and corroboratory field survey targeted at locations identified from the aerial photographs. However, it does not quantify the volume of sediment sources, their rate of production, or the caliber of the sediment produced. To better characterize the production and yield of sediment to the basin (including sediment derived from anthropogenic sources), we recommend an investigation of sediment delivery rates or sediment budget analysis based upon the construction of a conceptual model of geomorphic processes operating under current and historical periods, along with estimates of cumulative sediment production, storage and delivery to water courses for individual processes derived from a finite set of geomorphic processes. Further, by stratifying the Study Area into regions where certain geomorphic processes dominate according to geology, slope, land cover, and channel management, it is possible to extrapolate the estimated process rates into a large portion of the basin not surveyed during this assessment. This will allow a more confident estimate of the average annual sediment yield. Data for this analysis would be collected with the specific goal of distinguishing natural background rates of sediment production from rates attributable to anthropogenic sources, and subdividing geomorphic process rates where possible according to their correspondence with climatic wet and dry periods.

These data would be used to develop summary maps of sediment delivery that indicate priority concerns and locations for controlling sediment production and deposition over broader areas than the current survey, and with better control on the relative contribution of natural and anthropogenic sources, so allowing for the development of targeted, process-based, management actions focused especially on reducing "excess" fine sediment production. Linking these estimates of sediment delivery rates with instream habitat and water quality monitoring should allow documentation of the effectiveness over time of efforts to reduce sediment inputs through abatement strategies.

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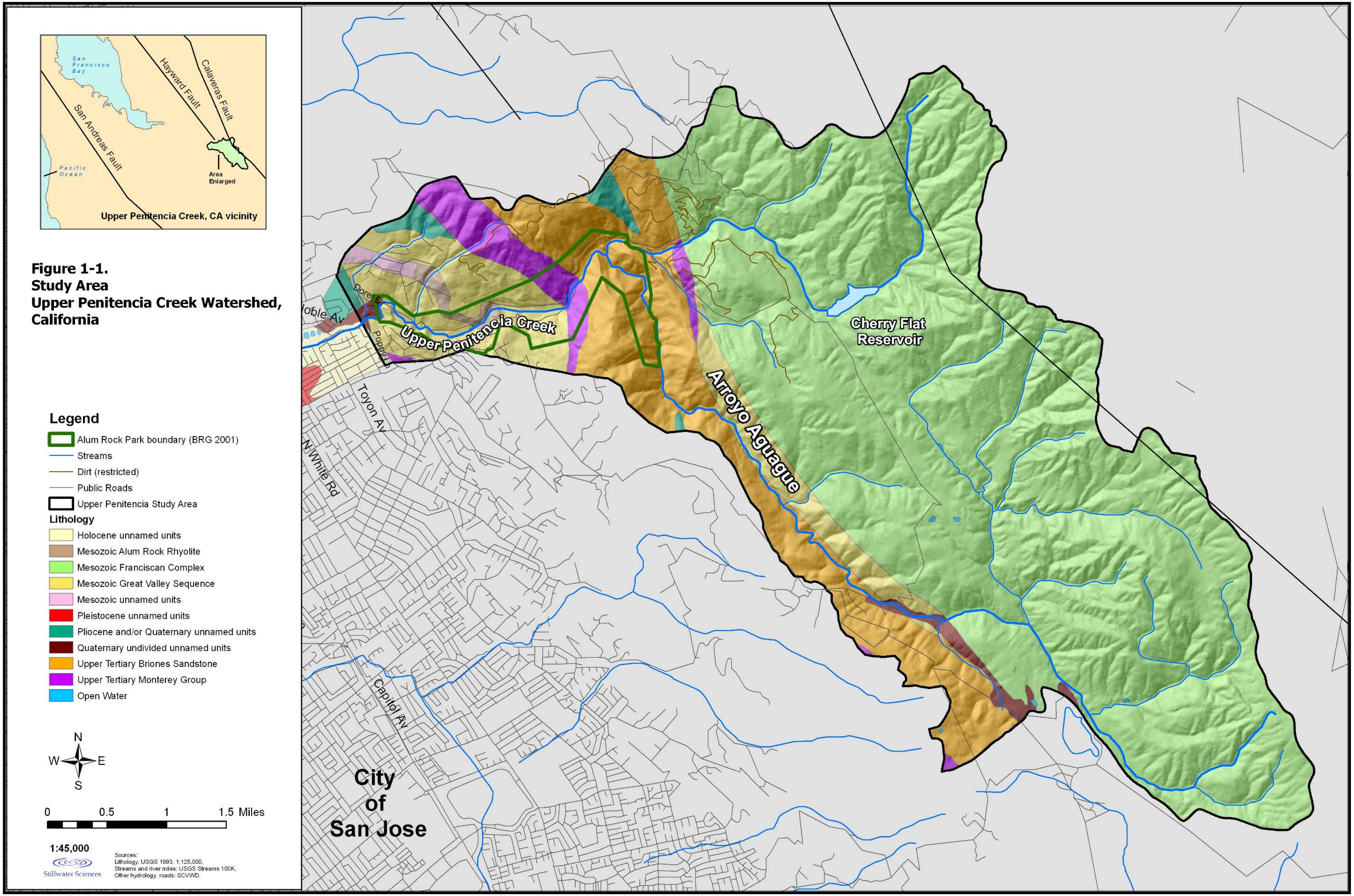
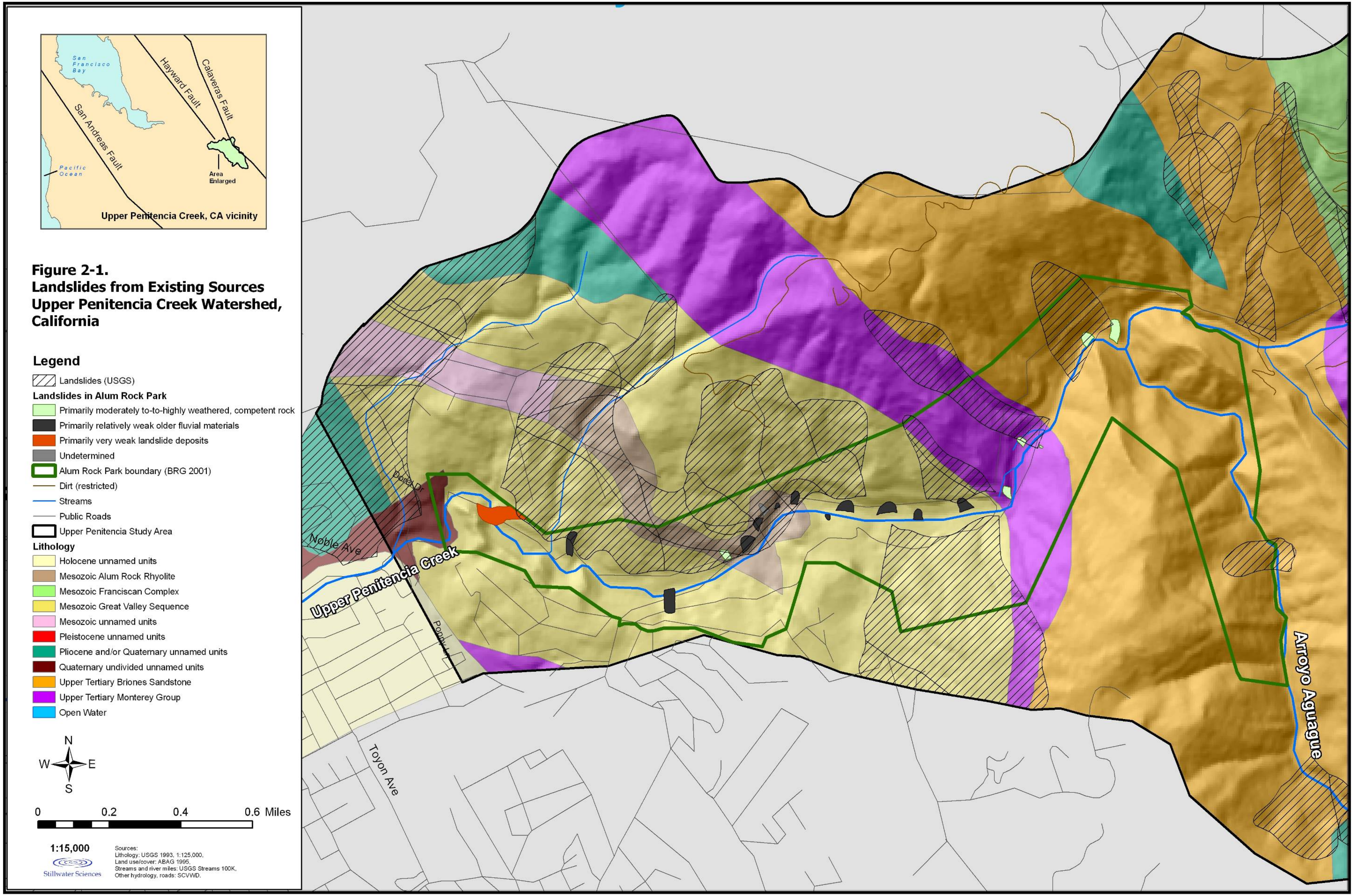
# FIGURES

Figure 1-1.
Study Area
Upper Penitencia Creek Watershed,
California



Sources:
Lithology: USGS 1993, 1:125,000,
Streams and river miles: USGS Streams 100K,
Other hydrology, roads: SCVWD.



## Figure 2-1.
## Landslides from Existing Sources Upper Penitencia Creek Watershed, California

San Francisco Bay
Hayward Fault
Calaveras Fault
San Andreas Fault
Pacific Ocean
Area Enlarged
Upper Penitencia Creek, CA vicinity
Legend
▨ Landslides (USGS)
Landslides in Alum Rock Park
🟩 Primarily moderately to-to-highly weathered, competent rock
⬛ Primarily relatively weak older fluvial materials
🟧 Primarily very weak landslide deposits
⬛ Undetermined
🟩 Alum Rock Park boundary (BRG 2001)
Dirt (restricted)
Streams
Public Roads
☐ Upper Penitencia Study Area
Lithology
🟨 Holocene unnamed units
🟫 Mesozoic Alum Rock Rhyolite
🟩 Mesozoic Franciscan Complex
🟨 Mesozoic Great Valley Sequence
🟪 Mesozoic unnamed units
🟥 Pleistocene unnamed units
🟩 Pliocene and/or Quaternary unnamed units
🟫 Quaternary undivided unnamed units
🟧 Upper Tertiary Briones Sandstone
🟪 Upper Tertiary Monterey Group
🟦 Open Water
N
W
E
S
0
0.2
0.4
0.6 Miles
1:15,000
Stillwater Sciences
Upper Penitencia Creek
Arroyo Aguague
Noble Ave
Dorel Dr
Pony Ln
Toyon Ave

Sources:
Lithology: USGS 1993, 1:125,000.
Land use/cover: ABAG 1995.
Streams and river miles: USGS Streams 100K.
Other hydrology, roads: SCVWD.

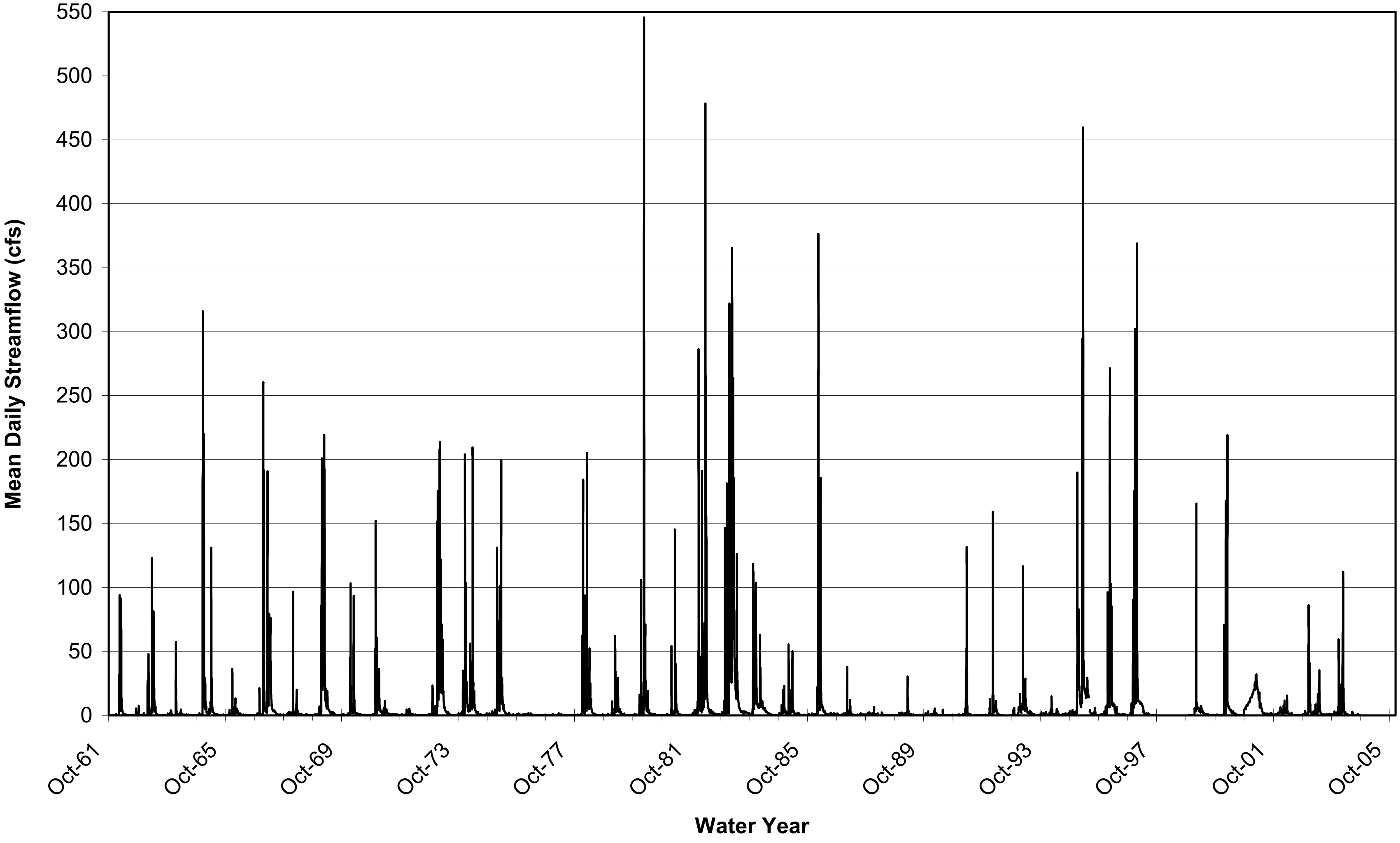
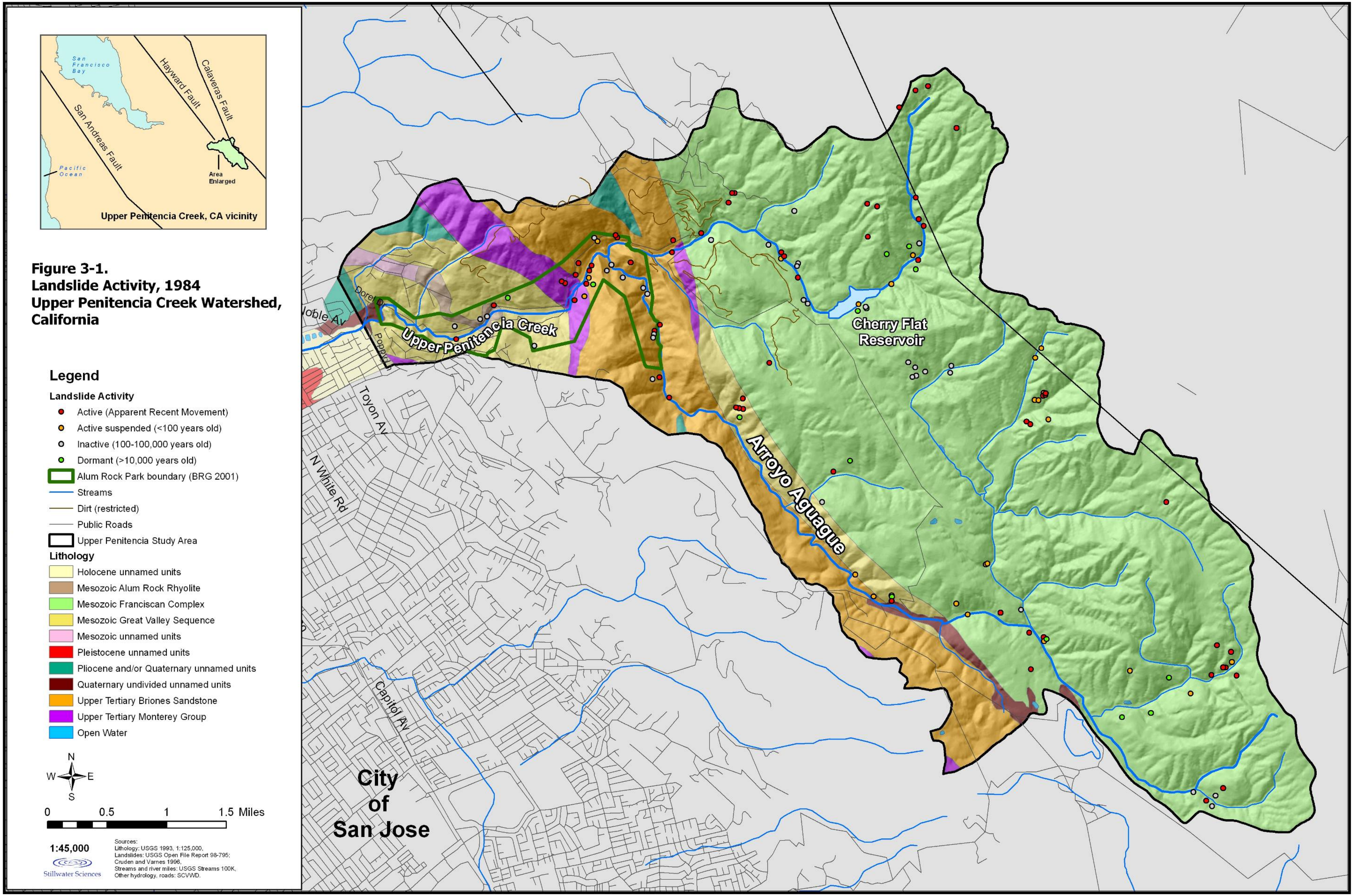


**Figure 2-2.** Mean daily streamflow in Upper Penitencia Creek at SCVWD gage SF 83 at Dorel Drive, Water Years 1962-2004.

**Figure 3-1.**
**Landslide Activity, 1984**
**Upper Penitencia Creek Watershed, California**


San Francisco Bay
Pacific Ocean
San Andreas Fault
Hayward Fault
Calaveras Fault
Area Enlarged
Upper Penitencia Creek, CA vicinity
Legend
Landslide Activity
● Active (Apparent Recent Movement)
● Active suspended (<100 years old)
○ Inactive (100-100,000 years old)
● Dormant (>10,000 years old)
Alum Rock Park boundary (BRG 2001)
Streams
Dirt (restricted)
Public Roads
Upper Penitencia Study Area
Lithology
Holocene unnamed units
Mesozoic Alum Rock Rhyolite
Mesozoic Franciscan Complex
Mesozoic Great Valley Sequence
Mesozoic unnamed units
Pleistocene unnamed units
Pliocene and/or Quaternary unnamed units
Quaternary undivided unnamed units
Upper Tertiary Briones Sandstone
Upper Tertiary Monterey Group
Open Water
N
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0.5
1
1.5 Miles
1:45,000
Stillwater Sciences
Upper Penitencia Creek
Cherry Flat Reservoir
Arroyo Aguague
Dorel Dr
Noble Av
Toyon Av
N White Rd
Capitol Av
City of San Jose

Sources:
Lithology: USGS 1993, 1:125,000,
Landslides: USGS Open File Report 98-795;
Cruden and Varnes 1996,
Streams and river miles: USGS Streams 100K,
Other hydrology, roads: SCVWD.

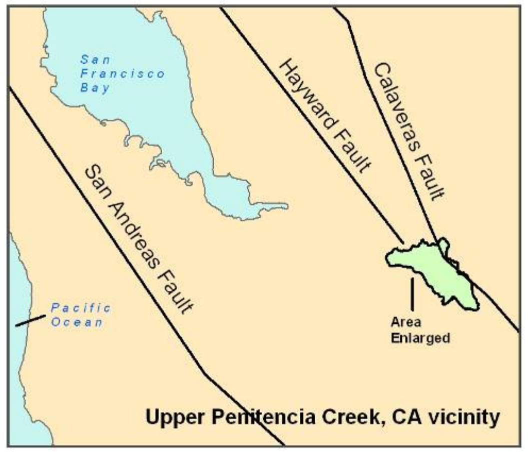
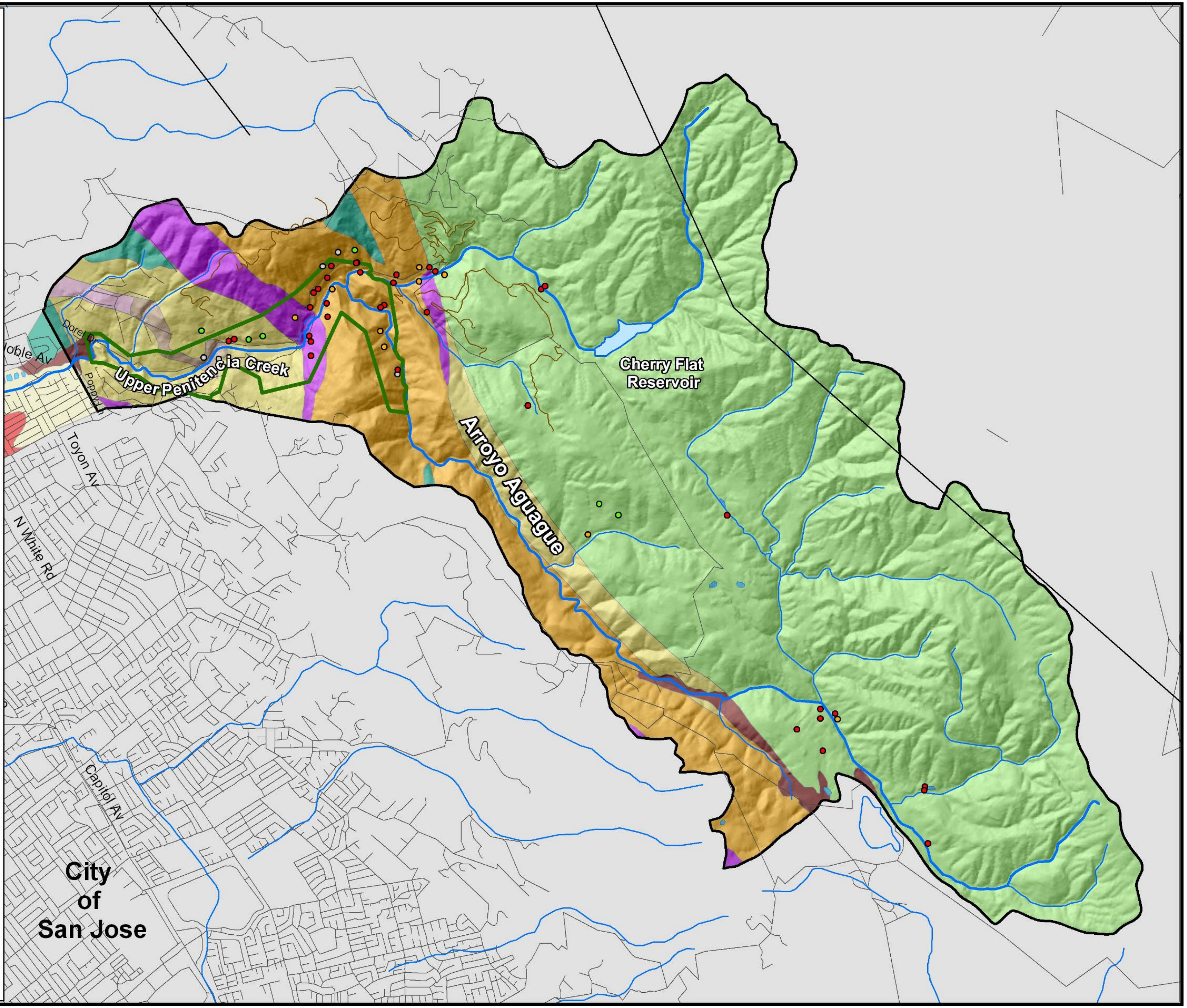


**Figure 3-2.
Landslide Activity, 1990
Upper Penitencia Creek Watershed,
California**



## Legend

**Landslide Activity**

- 🟥 Active (Apparent Recent Movement)
- ● Active suspended (<100 years old)
- ○ Inactive (100-100,000 years old)
- ● Dormant (>10,000 years old)
- ▭ Alum Rock Park boundary (BRG 2001)
- — Streams
- — Dirt (restricted)
- — Public Roads
- ▭ Upper Penitencia Study Area

**Lithology**

- ▨ Holocene unnamed units
- ▨ Mesozoic Alum Rock Rhyolite
- 🟩 Mesozoic Franciscan Complex
- 🟨 Mesozoic Great Valley Sequence
- ▨ Mesozoic unnamed units
- 🟥 Pleistocene unnamed units
- ▨ Pliocene and/or Quaternary unnamed units
- ▨ Quaternary undivided unnamed units
- 🟧 Upper Tertiary Briones Sandstone
- 🟪 Upper Tertiary Monterey Group
- 🟦 Open Water

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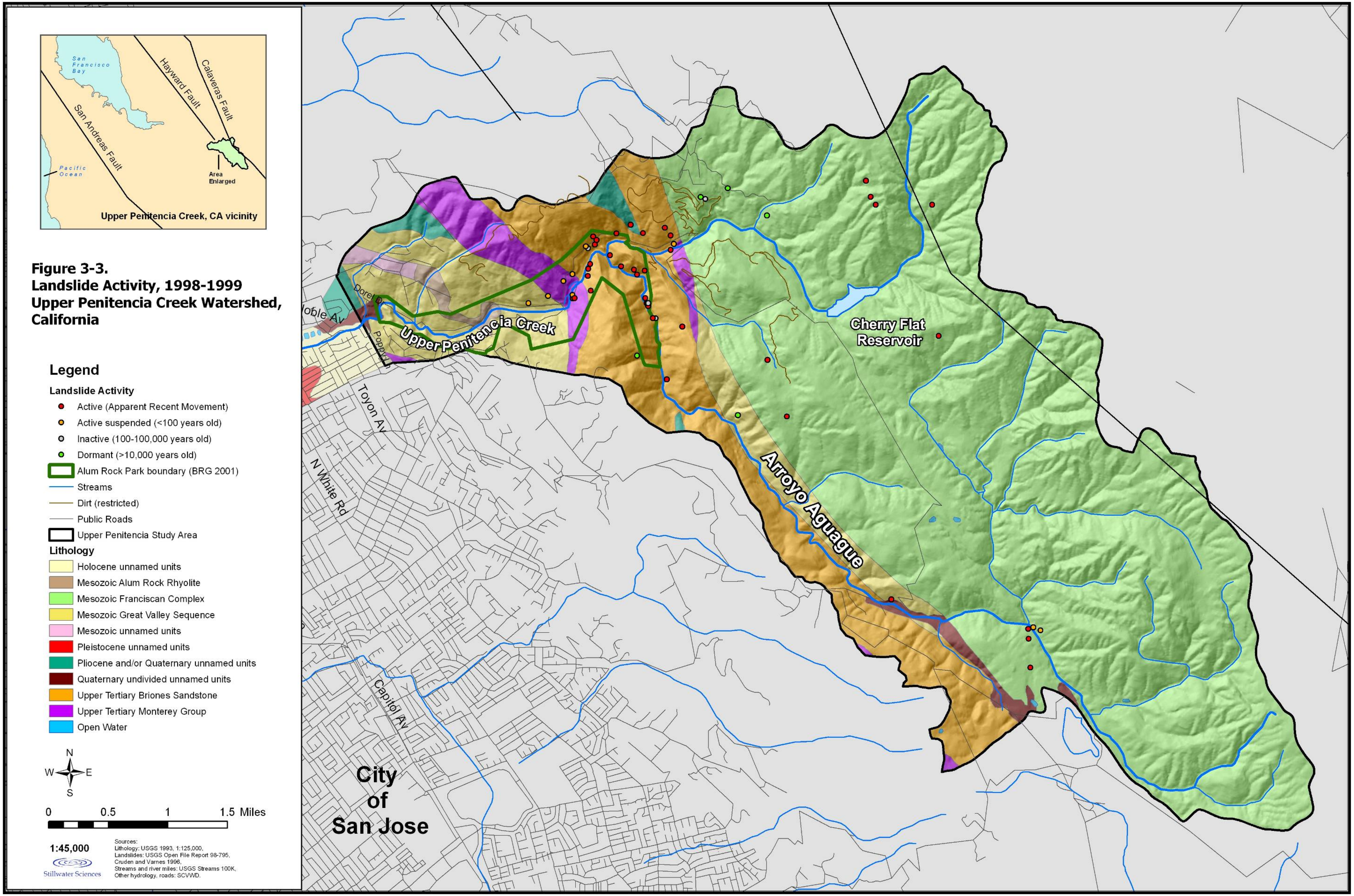
0 0.5 1 1.5 Miles

1:45,000

Stillwater Sciences

Sources:
Lithology: USGS 1993, 1:125,000,
Landslides: USGS Open File Report 98-795;
Cruden and Varnes 1996,
Streams and river miles: USGS Streams 100K,
Other hydrology, roads: SCVWD.

Figure 3-3.
Landslide Activity, 1998-1999
Upper Penitencia Creek Watershed,
California


San Francisco Bay
Hayward Fault
Calaveras Fault
San Andreas Fault
Pacific Ocean
Area Enlarged
Upper Penitencia Creek, CA vicinity
Legend
Landslide Activity
● Active (Apparent Recent Movement)
● Active suspended (<100 years old)
○ Inactive (100-100,000 years old)
● Dormant (>10,000 years old)
Alum Rock Park boundary (BRG 2001)
Streams
Dirt (restricted)
Public Roads
Upper Penitencia Study Area
Lithology
Holocene unnamed units
Mesozoic Alum Rock Rhyolite
Mesozoic Franciscan Complex
Mesozoic Great Valley Sequence
Mesozoic unnamed units
Pleistocene unnamed units
Pliocene and/or Quaternary unnamed units
Quaternary undivided unnamed units
Upper Tertiary Briones Sandstone
Upper Tertiary Monterey Group
Open Water
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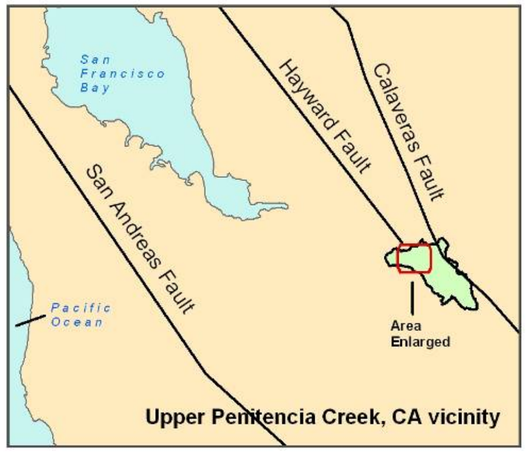
1.5 Miles
1:45,000
Stillwater Sciences
Upper Penitencia Creek
Arroyo Aguague
Cherry Flat Reservoir
Dorel Dr
Noble Av
Toyon Av
N White Rd
Capitol Av
City of San Jose

Sources:
Lithology: USGS 1993, 1:125,000,
Landslides: USGS Open File Report 98-795,
Cruden and Varnes 1996,
Streams and river miles: USGS Streams 100K,
Other hydrology, roads: SCVWD.



## Figure 3-4a
## Field Mapped Landslides, 2007 Upper Penitencia Creek Watershed, California

**Legend**

- 🟨 April 2007 SWS field verified inventory
- ▭ Alum Rock Park boundary (BRG 2001)
- — Streams
- 🟦 Percolation Ponds
- — Dirt (restricted)
- — Public Roads
- ▭ Upper Penitencia Study Area

**Lithology**

- 🟨 Holocene unnamed units
- 🟫 Mesozoic Alum Rock Rhyolite
- 🟩 Mesozoic Franciscan Complex
- 🟨 Mesozoic Great Valley Sequence
- 🟪 Mesozoic unnamed units
- 🟥 Pleistocene unnamed units
- 🟩 Pliocene and/or Quaternary unnamed units
- 🟫 Quaternary undivided unnamed units
- 🟧 Upper Tertiary Briones Sandstone
- 🟪 Upper Tertiary Monterey Group
- 🟦 Open Water

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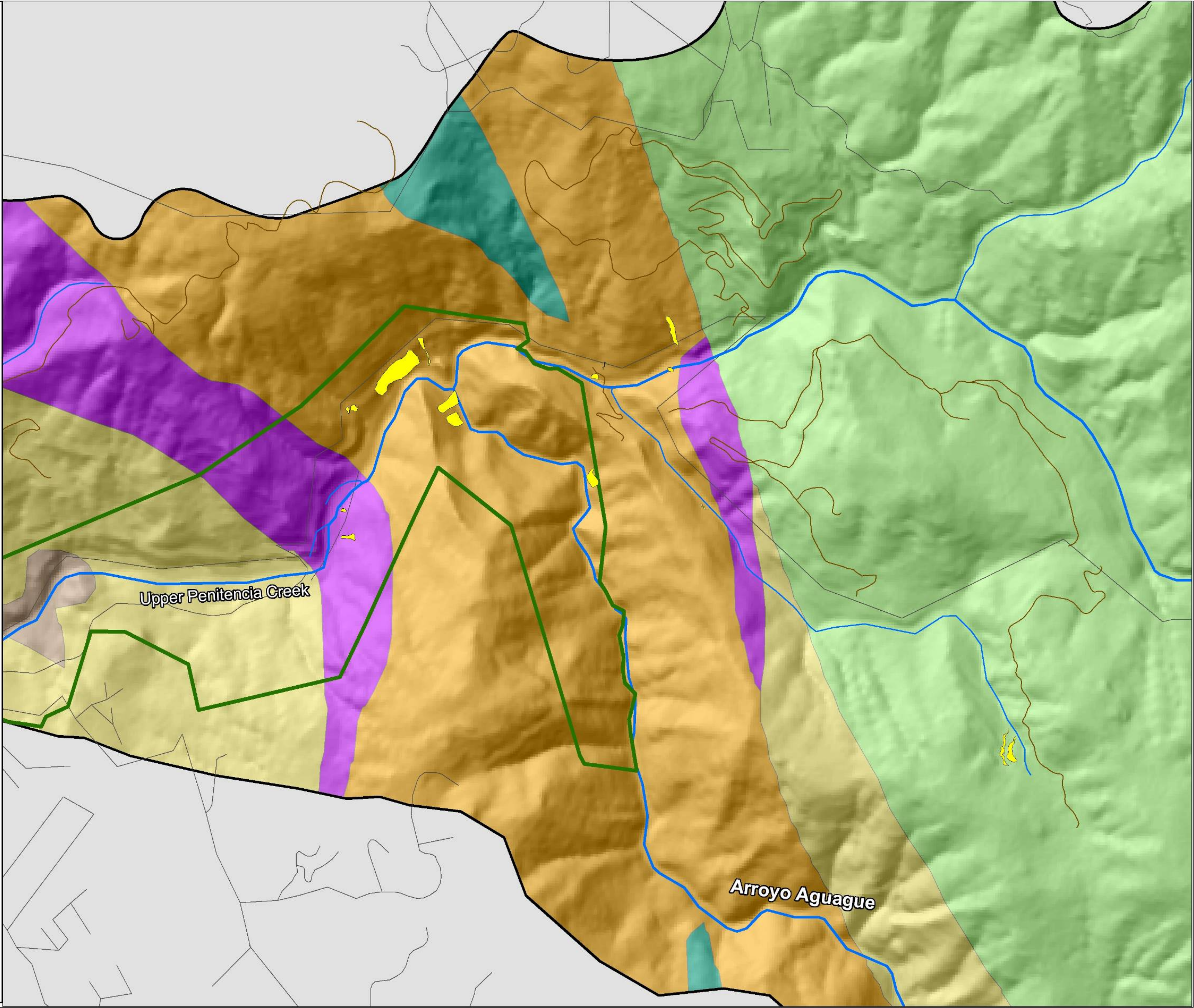
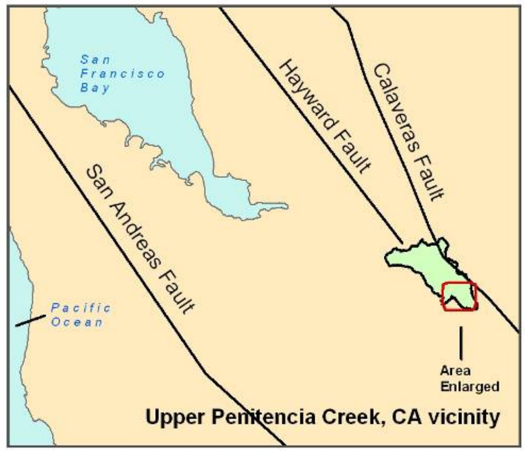
0 1,000 2,000 3,000 Feet

1:15,000

Stillwater Sciences

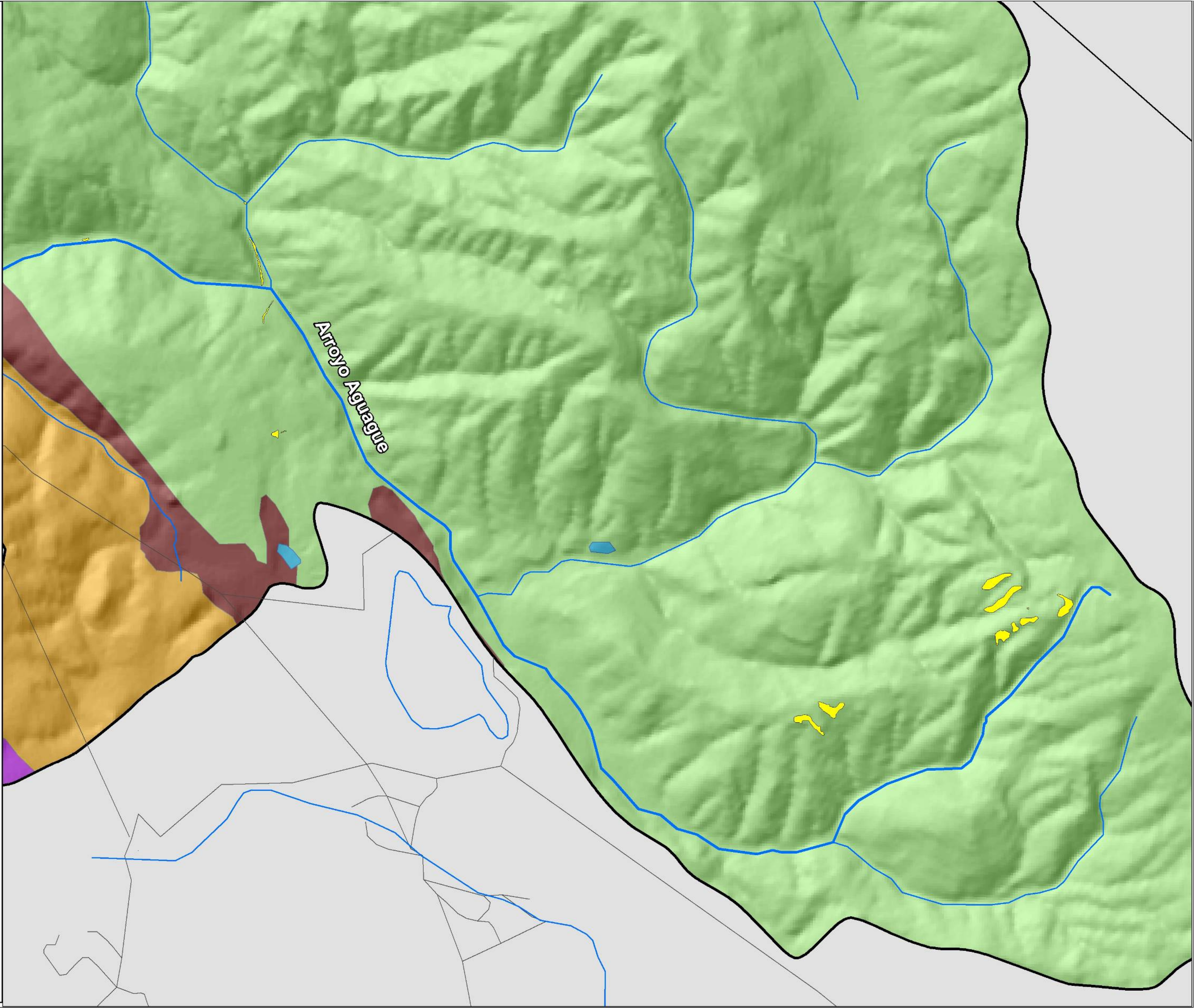
Sources:
Lithology: USGS 1993, 1:125,000,
Landslides: Stillwater Sciences 2007,
Streams and river miles: USGS Streams 100K,
Other hydrology, roads: SCVWD.





Upper Penitencia Creek, CA vicinity

## Figure 3-4b
## Field Mapped Landslides, 2007 Upper Penitencia Creek Watershed, California



### Legend

- 🟨 April 2007 SWS field verified inventory
- ▭ Alum Rock Park boundary (BRG 2001)
- — Streams
- 🟦 Percolation Ponds
- — Dirt (restricted)
- — Public Roads
- ▭ Upper Penitencia Study Area

**Lithology**

- 🟨 Holocene unnamed units
- 🟫 Mesozoic Alum Rock Rhyolite
- 🟩 Mesozoic Franciscan Complex
- 🟨 Mesozoic Great Valley Sequence
- 🟪 Mesozoic unnamed units
- 🟥 Pleistocene unnamed units
- 🟩 Pliocene and/or Quaternary unnamed units
- 🟫 Quaternary undivided unnamed units
- 🟧 Upper Tertiary Briones Sandstone
- 🟪 Upper Tertiary Monterey Group
- 🟦 Open Water

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0 1,000 2,000 3,000 Feet

1:15,000

Stillwater Sciences

Sources:
Lithology: USGS 1993, 1:125,000,
Landslides: Stillwater Sciences 2007,
Streams and river miles: USGS Streams 100K,
Other hydrology, roads: SCVWD.

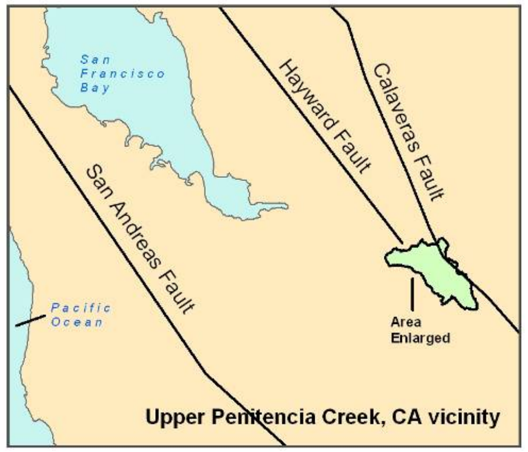
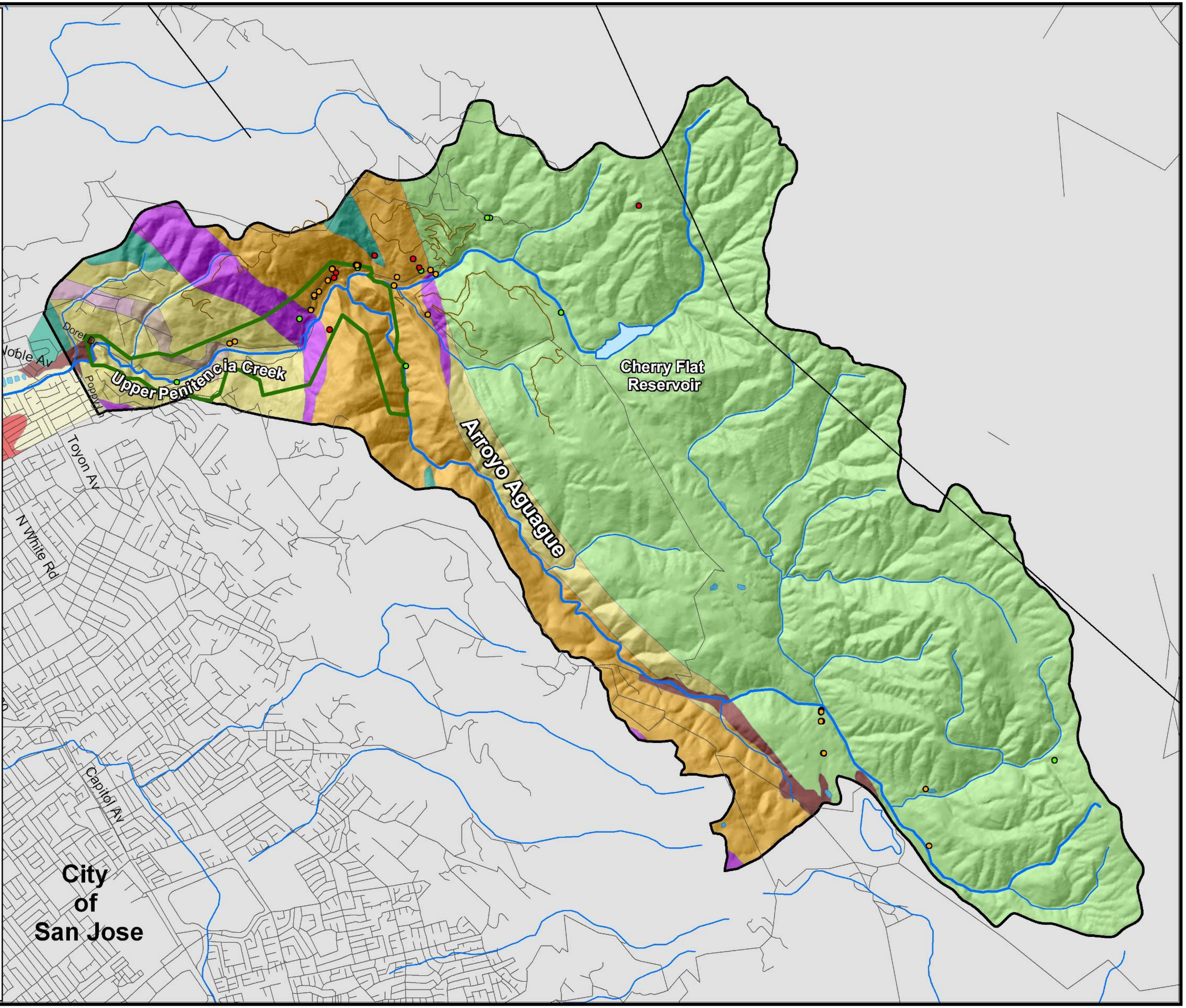


**Figure 4-1.**
**Road Associated Active Features Upper Penitencia Creek Watershed, California**


Dorel Dr
Noble Av
Poppy
Upper Penitencia Creek
Cherry Flat Reservoir
Arroyo Aguague
Toyon Av
N White Rd
Capitol Av
City of San Jose
Legend
1984
1990
1998- 1999
Alum Rock Park boundary (BRG 2001)
Streams
Dirt (restricted)
Public Roads
Upper Penitencia Study Area
Lithology
Holocene unnamed units
Mesozoic Alum Rock Rhyolite
Mesozoic Franciscan Complex
Mesozoic Great Valley Sequence
Mesozoic unnamed units
Pleistocene unnamed units
Pliocene and/or Quaternary unnamed units
Quaternary undivided unnamed units
Upper Tertiary Briones Sandstone
Upper Tertiary Monterey Group
Open Water
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1.5 Miles
1:45,000
Stillwater Sciences

Sources:
Lithology: USGS 1993, 1:125,000,
Landslides: Stillwater Sciences 2007,
Streams and river miles: USGS Streams 100K,
Other hydrology, roads: SCVWD.

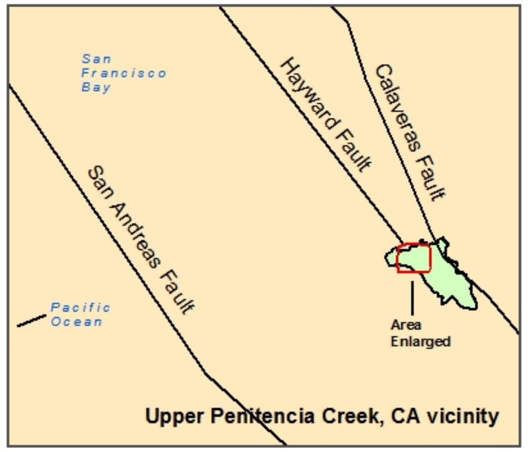
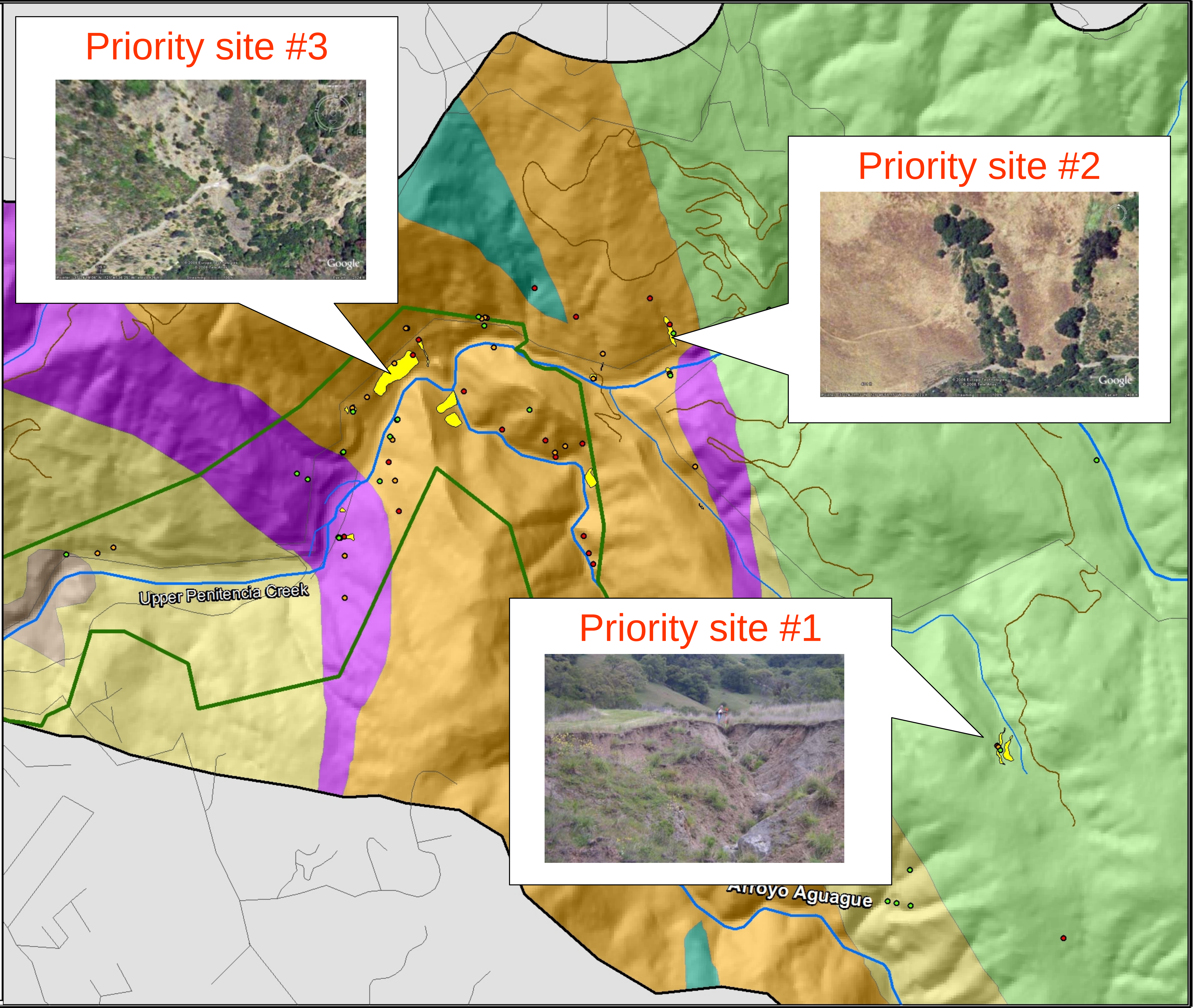


**Figure 4-2a.**
**Priority Concerns for Controlling Sediment Supply Upper Penitencia Creek Watershed, California**



## Legend

**Active Landslides**

- 🟢 1984
- 🟠 1990
- 🔴 1998-1999

- 🟨 April 2007 SWS field verified inventory
- ▢ Alum Rock Park boundary (BRG 2001)
- — Streams
- 🟦 Percolation Ponds
- — Dirt (restricted)
- — Public Roads
- ▢ Upper Penitencia Study Area

**Lithology**

- 🟨 Holocene unnamed units
- 🟫 Mesozoic Alum Rock Rhyolite
- 🟩 Mesozoic Franciscan Complex
- 🟨 Mesozoic Great Valley Sequence
- 🟪 Mesozoic unnamed units
- 🟥 Pleistocene unnamed units
- 🟩 Pliocene and/or Quaternary unnamed units
- 🟫 Quaternary undivided unnamed units
- 🟧 Upper Tertiary Briones Sandstone
- 🟪 Upper Tertiary Monterey Group
- 🟦 Open Water

0 1,000 2,000 3,000 Feet

1:15,000

Stillwater Sciences

Sources:
Lithology: USGS 1993, 1:125,000,
Landslides: Stillwater Sciences 2007,
Streams and river miles: USGS Streams 100K,
Other hydrology, roads: SCVWD.

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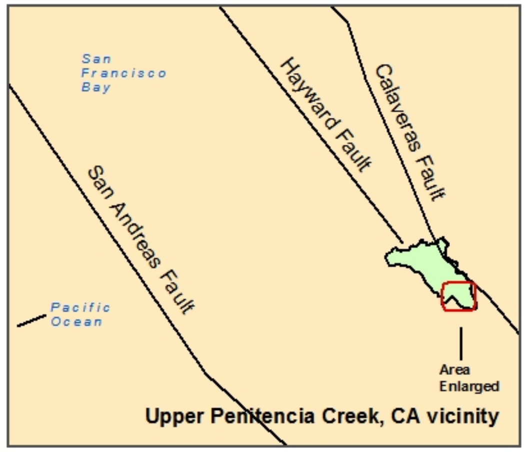
S



# Figure 4-2b
# Priority Concerns for Controlling Sediment Supply
# Upper Penitencia Creek Watershed, California

## Legend

**Active Landslides**

- ● 1984
- ● 1990
- ● 1998-1999

- 🟨 April 2007 SWS field verified inventory
- 🟩 Alum Rock Park boundary (BRG 2001)
- — Streams
- 🟦 Percolation Ponds
- — Dirt (restricted)
- — Public Roads
- ⬜ Upper Penitencia Study Area

**Lithology**

- ▨ Holocene unnamed units
- ▨ Mesozoic Alum Rock Rhyolite
- ▨ Mesozoic Franciscan Complex
- ▨ Mesozoic Great Valley Sequence
- ▨ Mesozoic unnamed units
- ▨ Pleistocene unnamed units
- ▨ Pliocene and/or Quaternary unnamed units
- ▨ Quaternary undivided unnamed units
- ▨ Upper Tertiary Briones Sandstone
- ▨ Upper Tertiary Monterey Group
- ▨ Open Water

0 1,000 2,000 3,000 Feet

1:15,000

Stillwater Sciences

Sources:
Lithology: USGS 1993, 1:125,000,
Landslides: Stillwater Sciences 2007,
Streams and river miles: USGS Streams 100K,
Other hydrology, roads: SCVWD.

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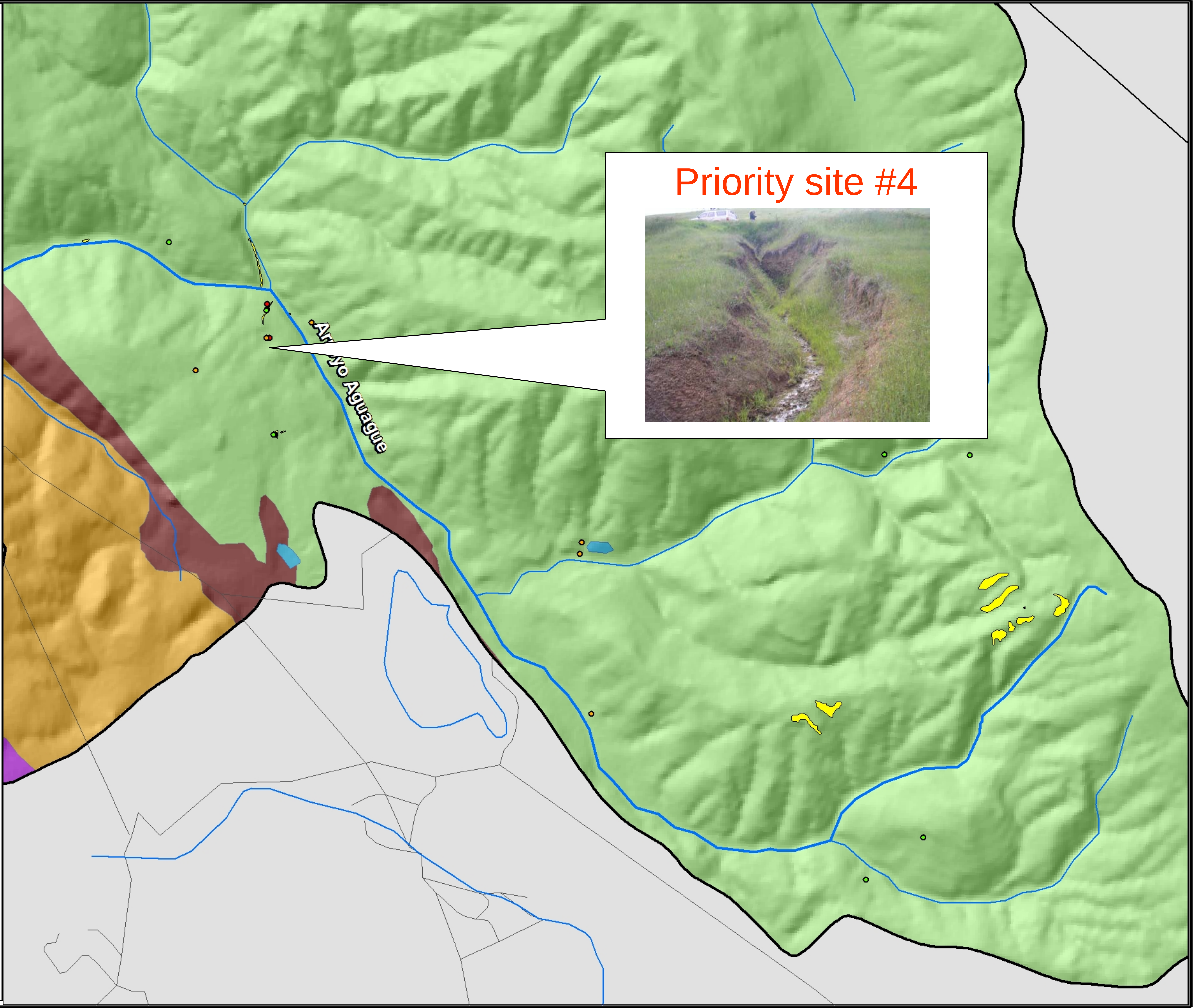

# Appendix A

# Landslide Gazetteer

**Table A-1.** The number and area of mass wasting features mapped from 1984 air photos by lithology, vegetation, and feature types.

| **Vegetation Type** | **Feature Type** | **Lithologic Unit** | | | | | | | | **GRAND TOTAL** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Franciscan** | | **Great Valley** | | **Briones sandstone** | | **Monterey group** | | | |
| | | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** |
| **Forest** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | 1 | 1,060 | 1 | 1,060 |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Forest Total** | | | | | | | **1** | **1,060** | **1** | **1,060** |
| **Forest/shrub** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | 1 | 40,601 | | | 1 | 40,601 |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | 1 | 140,281 | | | 1 | 140,281 |
| | **Forest/shrub Total** | | | | | **2** | **180,882** | | | **2** | **180,882** |
| **Grassland** | Channel bank erosion | 1 | 846 | | | | | | | 1 | 846 |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | 4 | 13,366 | | | | | | | 4 | 13,366 |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | 7 | 13,032 | | | | | | | 7 | 13,032 |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | 5 | 37,738 | | | | | | | 5 | 37,738 |
| | Slump earthflow | 1 | 1,329 | | | | | | | 1 | 1,329 |
| | Translational/rotational slide | | | | | | | | | | |
| | **Grassland Total** | **18** | **66,311** | | | | | | | **18** | **66,311** |
| **Riparian** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | 2 | 12,678 | | | 2 | 27,894 | | | 4 | 40,573 |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | 1 | 7,733 | | | | | | | 1 | 7,733 |

| **Vegetation Type** | **Feature Type** | **Lithologic Unit** | | | | | | | | **GRAND TOTAL** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Franciscan** | | **Great Valley** | | **Briones sandstone** | | **Monterey group** | | | |
| | | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Riparian Total** | **3** | **20,412** | | | **2** | **27,894** | | | **5** | **48,306** |
| **Shrub/forest** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | 2 | 32,217 | | | 2 | 32,217 |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Shrub/forest Total** | | | | | **2** | **32,217** | | | **2** | **32,217** |
| **Shrubland** | Channel bank erosion | 1 | 7,947 | | | | | | | 1 | 7,947 |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | 9 | 47,247 | | | 2 | 43,092 | | | 11 | 90,339 |
| | Debris slide slope | 1 | 21,546 | | | 1 | 138,589 | | | 2 | 160,135 |
| | Earthflow | | | | | | | | | | |
| | Gully | 1 | 2,881 | | | | | | | 1 | 2,881 |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Shrubland Total** | **12** | **79,622** | | | **3** | **181,681** | | | **15** | **261,303** |
| **Unvegetated** | Channel bank erosion | 1 | 1,022 | | | | | | | 1 | 1,022 |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | 6 | 9,834 | 4 | 8,970 | 7 | 13,441 | | | 17 | 32,245 |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | 1 | 5,651 | 1 | 5,651 |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Unvegetated Total** | **7** | **10,857** | **4** | **8,970** | **7** | **13,441** | **1** | **5,651** | **19** | **38,918** |
| **1984 TOTAL** | | **40** | **177,201** | **4** | **8,970** | **16** | **436,115** | **2** | **6,711** | **62** | **628,997** |

**Table A-2.** The number and area of mass wasting features mapped from 1990 air photos by lithology, vegetation, and feature types.

| **Vegetation Type** | **Feature Type** | **Lithologic Unit** | | | | | | | | **GRAND TOTAL** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Franciscan** | | **Great Valley** | | **Briones sandstone** | | **Monterey group** | | | |
| | | **#** | **Area (m$^2$)** | **#** | **Area (m$^2$)** | **#** | **Area (m$^2$)** | **#** | **Area (m$^2$)** | **#** | **Area (m$^2$)** |
| **Forest** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Forest Total** | | | | | | | | | | |
| **Forest/shrub** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | 1 | 2,542 | | | 1 | 2,542 |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Forest/shrub Total** | | | | | **1** | **2,542** | | | **1** | **2,542** |
| **Grassland** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | 4 | 4,611 | | | | | | | 4 | 4,611 |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | 1 | 1,452 | | | | | | | 1 | 1,452 |
| | Translational/rotational slide | | | | | | | | | | |
| | **Grassland Total** | **5** | **6,064** | | | | | | | **5** | **6,064** |
| **Riparian** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | 1 | 1,089 | | | | | | | 1 | 1,089 |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |

| Vegetation Type | Feature Type | Lithologic Unit | | | | | | | | GRAND TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Franciscan | | Great Valley | | Briones sandstone | | Monterey group | | | |
| | | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Riparian Total** | **1** | **1,089** | | | | | | | **1** | **1,089** |
| **Shrub/forest** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | 1 | 21,604 | | | 1 | 21,604 |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | 1 | 3,812 | | | | | | | 1 | 3,812 |
| | Translational/rotational slide | | | | | | | | | | |
| | **Shrub/forest Total** | **1** | **3,812** | | | **1** | **21,604** | | | **2** | **25,416** |
| **Shrubland** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | 2 | 5,446 | 1 | 726 | 4 | 86,960 | | | 7 | 93,132 |
| | Debris slide slope | | | 1 | 23,964 | 1 | 46,475 | | | 2 | 70,439 |
| | Earthflow | | | | | | | | | | |
| | Gully | 1 | 2,179 | | | 1 | 3,086 | | | 2 | 5,265 |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Shrubland Total** | **3** | **7,625** | **2** | **24,690** | **6** | **136,521** | | | **11** | **168,836** |
| **Unvegetated** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | 1 | 2,905 | 1 | 726 | 8 | 91,135 | | | 10 | 94,766 |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | 2 | 8,351 | | | | | | | 2 | 8,351 |
| | Rock slide | | | | | 1 | 7,625 | 1 | 3,631 | 2 | 11,256 |
| | Sheetwash/rill erosion | 1 | 2,542 | | | | | | | 1 | 2,542 |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Unvegetated Total** | **4** | **13,797** | **1** | **726** | **9** | **98,760** | **1** | **3,631** | **15** | **116,914** |
| **1990 TOTAL** | | **14** | **32,387** | **3** | **25,416** | **17** | **259,427** | **1** | **3,631** | **35** | **320,861** |

**Table A-3.** The number and area of mass wasting features mapped from 1998-1999 air photos by lithology, vegetation, and feature types.

| Vegetation Type | Feature Type | Lithologic Unit | | | | | | | | GRAND TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Franciscan | | Great Valley | | Briones sandstone | | Monterey group | | | |
| | | # | Area (m$^2$) | # | Area (m$^2$) | # | Area (m$^2$) | # | Area (m$^2$) | # | Area (m$^2$) |
| **Forest** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Forest Total** | | | | | | | | | | |
| **Forest/shrub** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | 1 | 24,508 | | | 1 | 24,508 |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Forest/shrub Total** | | | | | **1** | **24,508** | | | **1** | **24,508** |
| **Grassland** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | 1 | 19,970 | | | | | | | 1 | 19,970 |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | 7 | 23,782 | | | 1 | 47,383 | | | 8 | 71,165 |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | 2 | 261,424 | | | | | | | 2 | 261,424 |
| | Slump earthflow | 1 | 1,089 | | | | | | | 1 | 1,089 |
| | Translational/rotational slide | | | | | | | | | | |
| | **Grassland Total** | **11** | **306,265** | | | **1** | **47,383** | | | **12** | **353,648** |
| **Riparian** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | 1 | 4,357 | | | | | | | 1 | 4,357 |

| **Vegetation Type** | **Feature Type** | **Lithologic Unit** | | | | | | | | **GRAND TOTAL** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Franciscan** | | **Great Valley** | | **Briones sandstone** | | **Monterey group** | | | |
| | | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Riparian Total** | **1** | **4,357** | | | | | | | **1** | **4,357** |
| **Shrub/forest** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | 2 | 157,774 | | | 2 | 157,774 |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Shrub/forest Total** | | | | | **2** | **157,774** | | | **2** | **157,774** |
| **Shrubland** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | 1 | 46,104 | | | 1 | 46,104 |
| | Debris slide | 1 | 5,083 | | | 1 | 52,285 | 1 | 7,625 | 3 | 64,993 |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | 1 | 2,082 | | | 1 | 2,082 |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Shrubland Total** | **1** | **5,083** | | | **3** | **100,470** | **1** | **7,625** | **5** | **113,178** |
| **Unvegetated** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | 9 | 347,916 | | | 9 | 347,916 |
| | Debris slide slope | | | | | 2 | 66,536 | | | 2 | 66,536 |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | 2 | 83,510 | 2 | 83,510 |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | 1 | 908 | 1 | 908 |
| | **Unvegetated Total** | | | | | **11** | **414,452** | **3** | **84,418** | **14** | **498,870** |
| **1998-99 TOTAL** | | **13** | **315,705** | | | **18** | **744,588** | **4** | **92,043** | **35** | **1,152,336** |

# Appendix B

# Road-Related Landslide Gazetteer

**Table B-1.** The number and area of road related mass wasting features from 1984 air photos by lithology, vegetation, and feature types.

| Vegetation Type | Feature Type | Lithologic Unit | | | | | | | | GRAND TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Franciscan | | Great Valley | | Briones sandstone | | Monterey group | | | |
| | | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) |
| **Forest** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | **Forest Total** | | | | | | | | | | |
| **Forest/shrub** | Channel bank erosion | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | **Forest/shrub Total** | | | | | | | | | | |
| **Grassland** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | 2 | 4,462 | | | | | | | 2 | 4,462 |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | 1 | 1,329 | | | | | | | 1 | 1,329 |
| | Channel head advance | | | | | | | | | | |
| | **Grassland Total** | **3** | **5,791** | | | | | | | **3** | **5,791** |
| **Riparian** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | 2 | 27,894 | | | 2 | 27,894 |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |

| **Vegetation Type** | **Feature Type** | **Lithologic Unit** | | | | | | | | **GRAND TOTAL** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Franciscan** | | **Great Valley** | | **Briones sandstone** | | **Monterey group** | | | |
| | | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** | **#** | **Area ($m^2$)** |
| | Rock slide | 1 | 7,733 | | | | | | | 1 | 7,733 |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | **Riparian Total** | **1** | **7,733** | | | **2** | **27,894** | | | **3** | **35,628** |
| **Shrub/forest** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | 1 | 12,400 | | | 1 | 12,400 |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | **Shrub/forest Total** | | | | | **1** | **12,400** | | | **1** | **12,400** |
| **Shrubland** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | **Shrubland Total** | | | | | | | | | | |
| **Unvegetated** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | 3 | 4,945 | | | 5 | 10,104 | | | 8 | 15,049 |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | **Unvegetated Total** | **3** | **4,945** | | | **5** | **10,104** | | | **8** | **15,049** |
| | **1984 TOTAL** | **7** | **18,469** | | | **8** | **50,398** | | | **15** | **68,867** |

**Table B-2.** The number and area of road related mass wasting features from 1990 air photos by lithology, vegetation, and feature types.

| Vegetation Type | Feature Type | Lithologic Unit | | | | | | | | GRAND TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Franciscan | | Great Valley | | Briones sandstone | | Monterey group | | | |
| | | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) |
| **Forest** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | **Forest Total** | | | | | | | | | | |
| **Forest/shrub** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | **Forest/shrub Total** | | | | | | | | | | |
| **Grassland** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | 2 | 290 | | | | | | | 2 | 290 |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | 1 | 1,452 | | | | | | | 1 | 1,452 |
| | Channel head advance | | | | | | | | | | |
| | **Grassland Total** | **3** | **1,743** | | | | | | | **3** | **1,743** |
| **Riparian** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |

| Vegetation Type | Feature Type | Lithologic Unit |  |  |  |  |  |  |  | GRAND TOTAL |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Franciscan |  | Great Valley |  | Briones sandstone |  | Monterey group |  |  |  |
|  |  | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) |
|  | Rock slide |  |  |  |  |  |  |  |  |  |  |
|  | Sheetwash/rill erosion |  |  |  |  |  |  |  |  |  |  |
|  | Slump earthflow |  |  |  |  |  |  |  |  |  |  |
|  | Translational/rotational slide |  |  |  |  |  |  |  |  |  |  |
|  | Channel head advance |  |  |  |  |  |  |  |  |  |  |
|  | **Riparian Total** |  |  |  |  |  |  |  |  |  |  |
| **Shrub/forest** | Channel head advance |  |  |  |  |  |  |  |  |  |  |
|  | Debris flow |  |  |  |  |  |  |  |  |  |  |
|  | Debris slide |  |  |  |  |  |  |  |  |  |  |
|  | Debris slide slope |  |  |  |  |  |  |  |  |  |  |
|  | Earthflow |  |  |  |  |  |  |  |  |  |  |
|  | Gully |  |  |  |  |  |  |  |  |  |  |
|  | Rock slide |  |  |  |  |  |  |  |  |  |  |
|  | Sheetwash/rill erosion |  |  |  |  |  |  |  |  |  |  |
|  | Slump earthflow |  |  |  |  |  |  |  |  |  |  |
|  | Translational/rotational slide |  |  |  |  |  |  |  |  |  |  |
|  | Channel head advance |  |  |  |  |  |  |  |  |  |  |
|  | **Shrub/forest Total** |  |  |  |  |  |  |  |  |  |  |
| **Shrubland** | Channel head advance |  |  |  |  |  |  |  |  |  |  |
|  | Debris flow |  |  |  |  |  |  |  |  |  |  |
|  | Debris slide |  |  |  |  |  |  |  |  |  |  |
|  | Debris slide slope | 1 | 4,357 | 1 | 726 | 2 | 70,439 |  |  | 4 | 75,522 |
|  | Earthflow |  |  | 1 | 23,964 |  |  |  |  | 1 | 23,964 |
|  | Gully |  |  |  |  |  |  |  |  |  |  |
|  | Rock slide | 1 | 2,179 |  |  | 1 | 3,086 |  |  | 2 | 5,265 |
|  | Sheetwash/rill erosion |  |  |  |  |  |  |  |  |  |  |
|  | Slump earthflow |  |  |  |  |  |  |  |  |  |  |
|  | Translational/rotational slide |  |  |  |  |  |  |  |  |  |  |
|  | Channel head advance |  |  |  |  |  |  |  |  |  |  |
|  | **Shrubland Total** | **2** | **6,536** | **2** | **24,690** | **3** | **73,525** |  |  | **7** | **104,751** |
| **Unvegetated** | Channel head advance |  |  |  |  |  |  |  |  |  |  |
|  | Debris flow |  |  |  |  |  |  |  |  |  |  |
|  | Debris slide |  |  |  |  |  |  |  |  |  |  |
|  | Debris slide slope | 1 | 2,905 | 1 | 726 | 6 | 86,233 |  |  | 8 | 89,864 |
|  | Earthflow |  |  |  |  |  |  |  |  |  |  |
|  | Gully |  |  |  |  |  |  |  |  |  |  |
|  | Rock slide |  |  |  |  |  |  |  |  |  |  |
|  | Sheetwash/rill erosion |  |  |  |  |  |  |  |  |  |  |
|  | Slump earthflow | 1 | 2,542 |  |  |  |  |  |  | 1 | 2,542 |
|  | Translational/rotational slide |  |  |  |  |  |  |  |  |  |  |
|  | Channel head advance |  |  |  |  |  |  |  |  |  |  |
|  | **Unvegetated Total** | **2** | **5,446** | **1** | **726** | **6** | **86,233** |  |  | **9** | **92,406** |
|  | **1990 TOTAL** | **7** | **13,725** | **3** | **25,416** | **9** | **159,759** |  |  | **19** | **198,900** |

**Table B-3.** The number and area of road related mass wasting features from 1998-1999 air photos by lithology, vegetation, and feature types.

| Vegetation Type | Feature Type | Lithologic Unit | | | | | | | | GRAND TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Franciscan | | Great Valley | | Briones sandstone | | Monterey group | | | |
| | | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) |
| **Forest** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | **Forest Total** | | | | | | | | | | |
| **Forest/shrub** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | **Forest/shrub Total** | | | | | | | | | | |
| **Grassland** | Channel head advance | | | | | | | | | | |
| | Debris flow | 1 | 19,970 | | | | | | | 1 | 19,970 |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | 3 | 2,632 | | | | | | | 3 | 2,632 |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | 1 | 1,089 | | | | | | | 1 | 1,089 |
| | Channel head advance | | | | | | | | | | |
| | **Grassland Total** | **5** | **23,692** | | | | | | | **5** | **23,692** |
| **Riparian** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | | | | | | |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |

| Vegetation Type | Feature Type | Lithologic Unit | | | | | | | | GRAND TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Franciscan | | Great Valley | | Briones sandstone | | Monterey group | | | |
| | | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) | # | Area ($m^2$) |
| | Rock slide | 1 | 4,357 | | | | | | | 1 | 4,357 |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | **Riparian Total** | **1** | **4,357** | | | | | | | **1** | **4,357** |
| **Shrub/forest** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | 1 | 29,967 | | | 1 | 29,967 |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | **Shrub/forest Total** | | | | | **1** | **29,967** | | | **1** | **29,967** |
| **Shrubland** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | 1 | 46,104 | | | 1 | 46,104 |
| | Debris slide slope | | | | | | | 1 | 7,625 | 1 | 7,625 |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | 1 | 2,082 | | | 1 | 2,082 |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | **Shrubland Total** | | | | | **2** | **48,186** | **1** | **7,625** | **3** | **55,810** |
| **Unvegetated** | Channel head advance | | | | | | | | | | |
| | Debris flow | | | | | | | | | | |
| | Debris slide | | | | | | | | | | |
| | Debris slide slope | | | | | 2 | 31,575 | | | 2 | 31,575 |
| | Earthflow | | | | | | | | | | |
| | Gully | | | | | | | | | | |
| | Rock slide | | | | | | | | | | |
| | Sheetwash/rill erosion | | | | | | | | | | |
| | Slump earthflow | | | | | | | | | | |
| | Translational/rotational slide | | | | | | | | | | |
| | Channel head advance | | | | | | | | | | |
| | **Unvegetated Total** | | | | | **2** | **31,575** | | | **2** | **31,575** |
| | **1998-99 TOTAL** | **6** | **28,049** | | | **5** | **109,728** | **1** | **7,625** | **12** | **145,402** |